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Comprehensive Distribution and Characterization of Missouri's Glade-Producing Rock Formations

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Cover photograph: Pale purple and yellow coneflowers flourish on thin soils over dolomite bedrock on an expansive glade at Ha Ha Tonka State Park. Photo by Paul W. Nelson.

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Comprehensive Distribution and Characterization of Missouri's Glade-Producing Rock Formations

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Abstract

More than 97,000 glades, totaling 182,464 acres, occur on 18 distinct geologic bedrock formations in Missouri. This report covers glade mapping methodology including boundary determination, polygon assignment, and probability of errors for the glade geology ESRI shapefile, originally published in 2014. Glade distribution, landscape pattern, and statistical analysis demonstrate a relationship between glade development and both the geologic bedrock formation and the different bedrock lithologies within the formation. Of the bedrock formations in Missouri, five represent more than 95% of the glades mapped. The size of Missouri glades ranges from 0.01 acres to 968 acres with an average size of 1.9 acres. With the greatest acreage, the Jefferson City Dolomite was determined to total 132,216 acres or approximately 72.5% of the glades within the state. The Burlington and Keokuk limestones and the Gasconade Dolomite followed with 12,727 acres and 10,982 acres, respectively. Volcanic rock types produce 11,530 glades totaling 12,400 acres. With many glades present in Missouri, field confirmation of underlying bedrock formation for individual glades was not a keystone of this report, nor was the ecological quality of the individual glades. The best available geologic and ecologic mapping was used, and the authors fully expect further refinement as researchers continue to investigate Missouri's glade communities.

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ACKNOWLEDGMENTS

A sequence of collaborative events spanning nearly 10 years led to the development of two products presented in this technical report. The first is the comprehensive mapping of Missouri's glades resulting in the 2016 Missouri Natural Glades data layer. The second product is a refinement of the first shapefile, incorporating the assignment of geologic units to more than 97,000 Missouri glades.

The impetus for initiating the Missouri glade mapping project began with the production of the Central Hardwoods Joint Venture (CHJV) Glade Conservation Assessment (Nelson et al., 2013). Jane Fitzgerald, Ph.D. and Director of CHJV, and Paul W. Nelson, Forest Ecologist for the Mark Twain National Forest (MTNF) (retired) led a collaborative effort among eight states to document the status and distribution of 24 distinct glade ecosystems and their associated species of conservation concern within the CHJV planning region. Eight contributing authors along with 12 other state specialists (credited in the Assessment) provided the expertise to complete the Assessment. Conservation recommendations in the Assessment prioritized the completion of state glade inventories to aid in implementing conservation strategies. This recommendation initiated two monumental glade inventories for Missouri and Arkansas, respectively. The Ozark Highlands and Ouachita Mountains capture perhaps 80% of all known glades in the eastern half of the United States.

Under the auspices of the American Bird Conservancy (ABC) and CHJV, numerous partners provided funding and support to project leader Nelson to complete glade mapping in Missouri from 2012 to 2014. This resulted in the posting of the 2016 Missouri Natural Glades shapefile with the Missouri Spatial Data Information Service (MSDIS), and a virtual interactive natural glades map through the Gulf Coastal Plains and Ozark Landscape Conservation Cooperative (GCPO LCC). Organizations providing funding support for this mapping project include the American Bird Conservancy; GCPO LCC; U.S. Department of Agriculture, Forest Service; U.S. Fish and Wildlife Service; Missouri Department of Conservation (MDC); and the Forest and Wildlife Research Center at Mississippi State University. Natural Resource Ecologist Allison J. Vaughn agreed to serve as data steward on behalf of the Missouri Department of Natural Resources in preparing and posting the Missouri Natural Glades shapefile through MSDIS.

The aforementioned Missouri glade mapping project, culminating in the 2014 glade spatial data layer, subsequently provided the data framework from which to create the 2018 Natural Glades geology spatial data layer (Nelson et al., 2013) presented in this document. In 2016, CHJV licensed ArcGIS to Nelson, Natural Community Advisor to CHJV, to complete the task. When finished in 2019, Vaughn reissued a second edition of the shapefile to MSDIS, this time incorporating the geologic units into the metadata and shapefile.

This paper characterizes Missouri's glades based on various aspects and attributes of the geologic units in which they occur. Thus, it became imperative that Nelson and Vaughn employ the technical expertise essential toward differentiating the 18 glade-producing rock substrates and minimizing error in assigning the correct geologic unit to each glade. Nelson and Vaughn realized this work, although about glades, was a study in geology. Vaughn looked no further than Larry "Boot" Pierce, Jr., Chief of the Geologic Resources Section at the Missouri Geological Survey, a division of the Missouri Department of Natural Resources. Pierce called upon the in-kind services of field geologists throughout the state to visit various glade locations with the authors. It became apparent because of Missouri's complex and varied lithology, that identifying many rock types (or geologic units) required geological expertise, and that others interested in glade research cannot always depend on generalized geologic maps, nor their own field knowledge.

Field geologists provided expertise to examine and interpret various glade rock substrates. This aided in adjusting glade boundaries, correlating topographic patterns, and identifying the range of potential errors. The authors wish to thank Missouri Geological Survey field geologists Jeffrey "Spike" Crews, Trevor Ellis, Mike Siemens and Vicki Voigt for helping identify bedrock units underlying glades in problematic geologic areas, and Art Hebrank, a natural resource manager with Missouri State Parks, a division of the Missouri Department of Natural Resources.

Chapter 1.
Introduction and Project History

Prerequisite to any assessment, research, ecosystem characterization, management or protection is discovery. Whatever the specific area of interest, whether botany, zoology, geology, or the general nature enthusiast, every aspect of a glade's character is fascinating when discovered for the first time. The simple reason is that each is in some way different than the next. Their variability shapes their inherent diversity of life, and often the presence of restricted or endemic species. For the most part, glades are insular, meaning their biota is often distinct and isolated, often like islands in the sea. Missouri is an archipelago of glade islands – tens of thousands of them. Charles Darwin's discovery of the Galapagos Islands led to the profound, world-changing premise that species evolved and differentiated on islands. So, the fascination among various scientific disciplines interested in glades is the wonder of discovering new species, disjuncts, relicts, variable assemblages of biota, and explanations of environmental factors responsible for this variation. Every glade harbors a mix of these different elements and awaits discovery. And for the first time, glade enthusiasts no longer must wonder where Missouri glades are located.

The primary purpose of this report is to describe and analyze the results of assigning one of 18 distinct glade-producing geologic formations to Missouri's 97,286 glades culminating in the development of a glade geology shapefile. The authors systematically describe Missouri's glade distribution, topographic relationships, lithology, shape, size, and public locations for their conservation in each geologic unit. In addition, this work documents the methodology for mapping Missouri's glades that resulted in the posting of the initial natural glade shapefile in 2014, which served as the foundation for the development and completion of the glade geology spatial layer. The authors provide the data for purposes of conservation planning, environmental assessments, ecological stewardship, and alternative development actions to avoid inadvertent damage, public awareness and scientific study. A preliminary analysis of the layer statistics is discussed. Various figures, maps, tables and appendix present information and data comparing distribution, patterns, relative size, geologic history, lithology, isolation and other factors. The authors hope to encourage a broad range of scientific, interpretive, and educational interest aimed at expanding knowledge about Missouri's glade geology and biodiversity. Public land managing agencies, conservation organizations, and interested individuals should revisit conservation strategies based on the findings. While not all inclusive, perhaps the most important strategies should include a renewal of glade/woodland inventories, determining gaps in glade protection, and consider landscape-scale designs for targets based on reexamination of the map data. Glades (by definition) contain surficial exposures of bedrock, providing reference areas from which to identify or validate lithology. The best available geologic mapping was used to produce this report. Field observation of each individual glade was not possible thus some degree of error exists in the geologic unit assigned to each polygon. Researchers are encouraged to report any corrections as a means of periodically updating the glade geology shapefile.

Missouri's bedrock is highly varied, spanning nearly 1.5 billion years of geologic processes. Volcanoes formed the St. Francois Mountains, uplifts exposed sediments of ancient seas sediments, and erosion cycles carved Missouri's many streams and river courses. Throughout this time, glaciers (thousands of feet high) advanced southward covering the northern half of Missouri. Violent earthquakes faulted and fractured rock formations. Ancient rivers carved through bedrock depositing gravel, sand and silt in former valleys, while forming deltas along ocean shorelines. Erosion cycles from ocean regressions and weathering worked to create complex geologic disconformities across the landscape. Pressure and time solidified ocean sediments, river and wind-driven sands, and volcanic ash and lava into Missouri's varied rock types. These rock types primarily include sandstone, limestone, dolomite, granite, rhyolite, chert and shale.

Today, most Missouri bedrock is obscured and mantled by vegetation and thick soils derived from glacial till, loess deposits, weathered stony residuum, and water-deposited sediments (Starbuck, 2019). Geologists, ecologists and others can locate exposed bedrock in streambeds, cliffs, boulders, ledges, eroded steep hillsides, quarries, highway road cuts … and glades. But it is the glade that attracts attention to its unique natural community and geomorphic history. Many of those interested in the study and conservation of Missouri's natural glades have wondered and questioned their extent, locations, patterns, underlying geology, and varied flora and fauna. Which of Missouri's rock formations are the primary glade producers and how does that impact their distribution? Do the physical, hydrological, and chemical properties of bedrock underlying a glade result in distinct habitats for unique plants and animals beyond what we currently know? And if so, what are the conservation implications? Finding the answers to these and many other questions begins with a basic question. Where are all the glades located? So began a glade mapping effort.

In 2009, Nelson initiated an effort to map restorable glade natural communities in Missouri. The project culminated in 2014 with the mapping of 88,155 glades totaling more than 157,000 acres across 65 counties. Nelson and Vaughn subsequently created a natural glade shapefile made available to the Missouri Spatial Data Information Service (MSDIS) for ArcGIS users. The first 2014 Natural Glades shapefile assigned one of the five distinctive glade natural community rock substrate types, as described in "The Terrestrial Natural Communities of Missouri" (Nelson, 2010), to each mapped glade. Soon thereafter, the map became available to internet users, who can explore the virtual distribution and patterns of Missouri

glades on the Gulf Coastal Plains and Ozarks Landscape Conservation Cooperative (GCPO LCC) website.

Using the 2014 Natural Glades data layer, Nelson assigned all of the Missouri glades to specific rock substrate based on the underlying geologic formation. Pierce provided the essential geologic expertise to assist with the substrate determinations. This paper summarizes and analyzes the comprehensive spatial mapping of glade-producing geologic formations across Missouri and provides an in-depth explanation of the mapping methodology employed during the entire mapping process. Spatial analysis of geologic formations including their outcrop patterns, lithology, weathering characteristics, and other data are discussed and displayed.

Minimum size	0.01 acres
Maximum size	968 acres
Total acreage (sum)	182,347 acres
Mean size	1.9 acres
Minimum perimeter	0.02 mile
Maximum perimeter	56 miles
Total perimeter (sum)	26,915 miles
Mean perimeter	0.3 mile

Table 1-1. *Statistical summary of Missouri's 97,286 glades.*

Concurrent with the rock substrate determinations, the authors reexamined the glade map using the most recent higher resolution imagery made available through ESRI World Imagery. Previously unmapped or unchartered areas of the state that were not thought to contain glades were reexamined. As a result, the 2018 revised count is 97,286 glades totaling 182,347 acres, an increase of 9,131 glades and 24,756 acres from the 2014 project (Table 1-1). This revised data is incorporated into the current 2018 Natural Glades data layer that replaces the 2014 version in MSDIS.

Data disclaimer: The numbers, completeness, boundary accuracy, delineated rock type, and results of analysis herein of the glade rock shapefile are subject to refinement and future iterations. The data analyzed in this document are based on the second iteration of the 2018 Missouri Natural Glades shapefile housed in MSDIS, University of Missouri, Department of Geography. The Missouri Department of Natural Resources (MoDNR) is the data steward for the shapefile, and periodically updates the data based on additional mapping refinement, field verifications, and other inventories. Future refinements will reveal human activities are modifying and destroying glades, which will alter the data.

The authors believe the glade map reflects a high degree of accuracy. The methodology and limitations for the quality of the imagery made it impossible to interpret and tease out otherwise image-obscured glades generally less than one-tenth acre. Additionally, any future efforts to squeeze additional small glades from the imagery would be time and cost prohibitive. The authors made clear the limitations of the methodology and encouraged refinements based on closer field examinations. Finally, the omission of small glades does not materially alter the otherwise relative distribution, patterns and ecological significance of glades mapped during this project.

GLADE MAPPING HISTORY

Glades have fascinated botanists, naturalists, ecologists and geologists for decades, resulting in a never-ending flow of scientific papers and popular articles. Many want to know "What is the extent, location and distribution pattern for certain glades of interest?" Having such data has implications for floristic surveys, plant and animal range extensions, data analysis, and conservation planning. In 1942, Ralph Erickson, Louis Brenner and Joseph Wraight pioneered the first effort to map the glades of east-central Missouri. Erickson initiated the mapping to study the distribution of Fremont's leather flower (*Clematis fremontii*). They painstakingly identified recognizable glades from aerial photographs taken in 1937 on file with the Agricultural Conservation Association. The resulting map featured approximately 3,500 glades transferred onto county highway maps. This 79-year-old hand-drawn map provided a moderately accurate rendering for the pattern and distribution of glades in Jefferson and a portion of Franklin counties. With respect for their intellectual history of the glade mapping concept, Erickson, Brenner and Wraight must be credited with the idea of original glade mapping work in Missouri. The current authors are fortunate, nearly 80 years later, to have the modern technology at their disposal to efficiently and effectively produce a comprehensive glade map for Missouri.

Published 40 years after Erickson et al. (1942), "The Preliminary Report on the Identification, Distribution, and Classification of Missouri Glades" (Nelson and Ladd, 1983) documented an effort to map Missouri's glades using aerial photographs. They commissioned the service of Janet Hicks, who completed a master's thesis study of the glades of Hercules Glades Wilderness (Hicks, 1981). Using a set of U.S. Geological Survey (USGS) 7.5' topographic quadrangle maps for portions of the Missouri Ozarks, Hicks used a magnifying stereoscope to identify glades and transfer the location. However, the time-consuming nature of this method precluded its use for the entire study. At best, the 1983 (Nelson and Ladd) report provided hand-drawn renderings of generalized locations on quadrangle maps for glade occurrences across portions of the Ozark Highlands. The resulting maps provided preliminary insight into the relationships between glade patterns, their distribution, topography and geology. Due to the limitations of the pencil-drawn glades, the authors made only estimates on the number and acres of glades. The Nelson and Ladd publication stated, "Undoubtedly as surveying continues and our knowledge of glade occurrence becomes more sophisticated, additional glades will be discovered."

ArcGIS, a geographic information system (GIS), allows users to visualize, analyze and interpret spatial data to answer questions about relationships, patterns and trends (source: Environmental Systems Research Institute at esri.com). Unlike the previous hand-drawings of glades on paper maps, Nelson drew glades using a mouse-driven tool that streams thousands of points, each having their own distinct latitude and longitude references. The result is a glade "polygon," which is digitally drawn as a series of connected XY coordinates forming a closed shape. ArcGIS offers a unique set of analytical-numerical tools used to calculate number of occurrences, area, perimeters, minimum, maximum, averages and means of these polygons.

Nelson initiated ArcGIS mapping of glades on MTNF after approval of the 2005 Forest Management Plan (FMP). The FMP set objectives for restoring specific acreages of glade natural communities across the Forest. The first step was to identify and map the glades on the MTNF. In 2009, ABC and the Forest Supervisor for MTNF collaborated with CHJV to expand the mapping throughout the Ozark Highlands. Upon his retirement from the Forest Service, Nelson contracted through ABC with funding from key support groups to complete mapping across 610 7.5′ quadrangles in Missouri. Vaughn assisted in this effort by mapping glades in Missouri State Parks, and throughout the Osage River Hills Ecological Subsection. Working for the Department of Natural Resources, she agreed to be the data steward and develop the metadata for the Natural Glades Shapefile housed in MSDIS. The authors completed the work in 2014 for the Ozark Highlands.

GLADE DEFINITION

Consensus on a definition is essential to minimize interpretations and variable mapping approaches often used by different ecologists. The following conditions characterize glades that were mapped in this project:

1. Glades are open, shallow-soil bedrock natural communities (Nelson, 2010) dominated by herbaceous flora.

2. Soil cover and depth is extremely thin ranging from less than 1 cm to 18 cm (as high as 30 cm on a few high-quality glades). Within this range of soil depths can occur several micro-associations of nonvascular and vascular flora. Bare, exposed bedrock is dominated by mosses and crustose lichens; ferns and some forbs grow from rock fractures. Along the periphery of exposed bedrock or in level bedrock depressions, gravel, silt and organic matter collects to develop soil as thick as 1 centimeter. Where ephemerally wet, *Nostoc*, *Tortella* and *Grimmia* mosses; reindeer lichens; and annual forbs and grasses are prominent. In soil 2 to 5 cm thick, woven mats of *Polytrichum* moss, reindeer moss, annual grasses and forbs develop. Vascular plants often include *Leavenworthia*, *Sedum* and *Cyperus* species. At soil depths greater than 5 cm, perennial grasses form the dominant matrix upon which many mixed perennial forbs prevail. As soil depth increases to 30 cm, mixed shrubs and stunted trees become prominent.

3. Depending on characteristics of the underlying geologic formation, the composition, structure, shape, and type of bedrock is highly variable. Bedrock exposures vary widely including layered sedimentary sandstones, dolomites and limestones, to massive solid igneous granites and rhyolites. These variations often include interspersed rock shelves and ledges, rock outcrops, car-sized boulders, flatrock surfaces, and scattered loose rocks of many sizes.

4. Ephemerally wet depressions, groundwater seepage, and temporary rivulets manifest themselves in ways distinctive to bedrock lithology. Some glade types collect precipitation and seepage runoff at the foot of the glade, often retaining highly organic, mucky or marly wet soil conditions.

5. Tree cover on good quality or restored glades (nearly absent of red cedar, *Juniperus virginiana*) is generally less than 10 to 30% and limited by frequent fire or drought conditions. Drought-tolerant and fire-sheltered trees or shrubs occur along rock shelves or deep bedrock fractures along with vines and (in crevices) drought-adapted ferns.

Chapter 2.
Glade Mapping Methodology

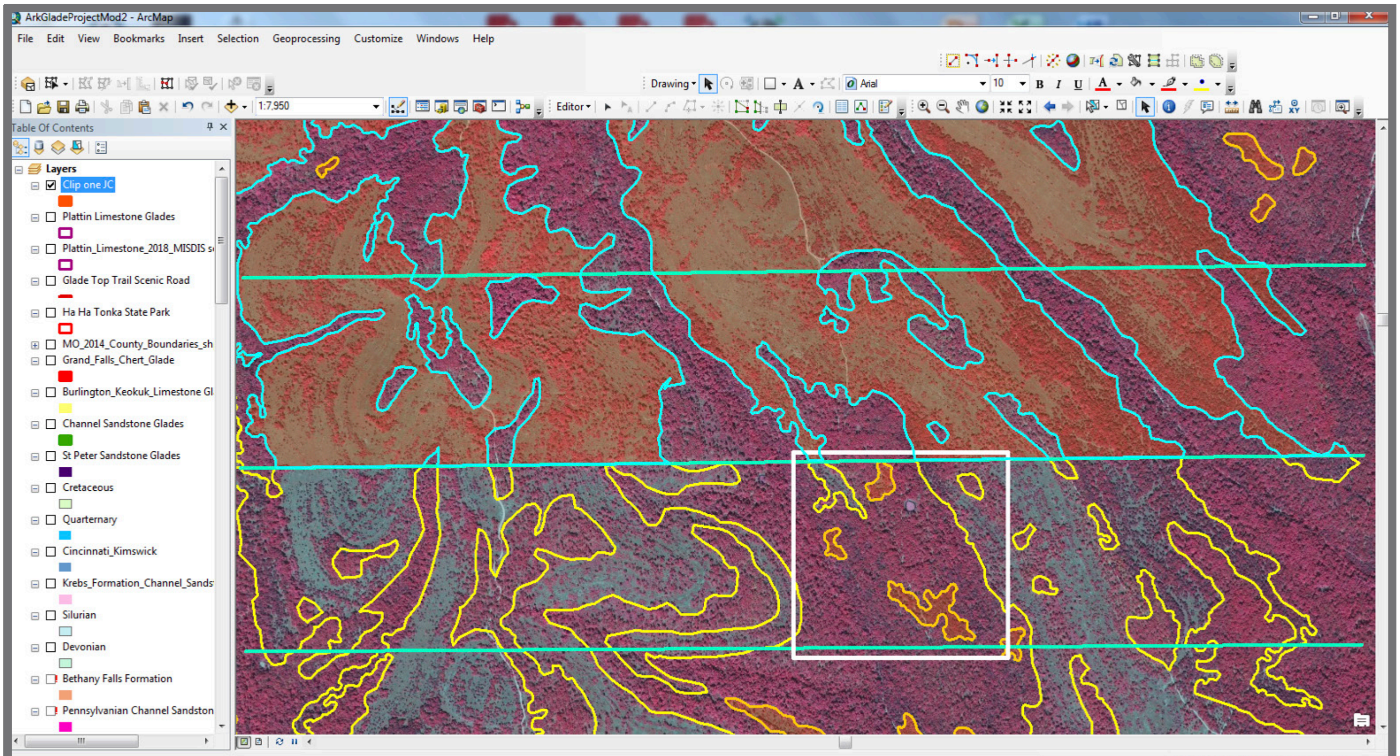

Figure 2-1. *An ArcView screenshot depicting spatial projection, layers (left) and tools used to systematically map glades across one of more than 600 7.5′ quadrangle maps (a portion of the Protem NE quadrangle map shown). The aerial image (NAIP infrared false color: glades shown are bluish gray) are geospatially virtual, meaning the boundaries represent numerical or degree latitude and longitude points that can be located using field GPS units.*

The 7.5′ topographic quadrangle map served as the base layer upon which all mapping was performed. At a scale of 1:24,000, one inch on the quad map represents 2,000 feet on the ground. Each geographically referenced quad map was downloaded into the ArcGIS computer screen platform (Fig. 2-1), then overlain by corresponding leaf-off aerial imagery, geologic maps, infrared imagery, soils mapping and other image data from various data sources (list follows). Each quad map was then divided into horizontal line grids approximately 1,500 feet wide and panned from top left to the bottom right across the grid using various images to locate and draw glades within a moving square frame (shown in platform). Mapping began in 2009 using ArcMap 9.3. This earlier version provided a polygon construction tool that set a vertex at each click of the mouse, resulting in borders consisting of angled lines. The latest ArcMap 10 version provided a freehand tool that streams smooth curved lines. This feature results in more accurate depiction of glade borders.

Missouri's Natural Heritage Database (MDC, Jefferson City) provided more than 1,400 Element Occurrence Records (EOR) for glades, and hundreds of EOR locations for glade-obligate plant and animal species. These locations aided in the initial selection of 400 quad maps and helped field validate mapped glade locations. In all, the authors systematically searched and mapped 610 of Missouri's 1,302 quadrangle maps for the occurrence of glades and tracked completed quad maps on Missouri's published topographic quadrangle index map.

GIS spatial layers and information used to map glades included:

a. USGS 7.5′ digital raster graphic topographic map and 1:24,000 quad maps provided by MSDIS.

b. USFS Infrared (IR) four band provided by the Missouri Resources Assessment Partnership (earlier infrared provided by USFS).

c. National Agricultural Imagery Program, NAIP specified 7.5′ quad maps provided by MSDIS.

d. USGS 2-foot resolution leaf-off aerial photography: specified 7.5′ quad maps provided by MSDIS, and ESRI World Imagery at one-meter-high resolution aerial photography.

e. Google Earth image selections for cross-referencing.

f. Natural Heritage Database: presence of EOR locations for glades and indicator species of conservation concern. Example: presence of EOR for *Liatris mucronata* in closed red cedar canopy.

g. Digital General Soil Map of the United States provided by U.S. Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS).

h. USDA-NRCS Missouri Soil Series descriptions. Information was useful to an extent, as some soil series include glades. However, soil boundaries do not match glade boundaries.

i. USGS mineral online spatial data, Missouri geology descriptions: used to generally delineate glade rock type. Refer to mapping limitations and errors for additional discussion.

j. Missouri Department of Natural Resources' Missouri Geological Survey 7.5' bedrock_geology shapefile provided by MSDIS.

k. MSDIS Imagery Server, Lidar: Found difficult to differentiate glade bedrock from rock outcrops in adjacent dry woodlands.

l. Missouri Department of Natural Resources, Missouri Geological Survey bedrock outcrop data layer shapefiles provided by Cheryl Seeger, Missouri Department of Natural Resources' Missouri Geological Survey.

m. Missouri Department of Agriculture, Division of Weights, Measures and Consumer Protection, Land Survey Program Missouri 2014 boundary shapefile and Missouri 2014 county shapefile compiled by Bruce L. Wilson, provided by MSDIS.

Mapping is an iterative process of interpreting and identifying the textures and colors of aerial images that signify the presence of glades. Accumulated mapping experience, coupled with field examinations, increased the power of focusing on and separating glade boundaries from a variety of challenging images. The authors discovered varying landscapes, glade types and image quality required selecting and cross-referencing those images that best signified glades. Tiles of aerial image quality varied based on remote sensing conditions, weather, time of day and season flown.

Not all maps or boundaries are perfectly aligned or justified. For example, the south boundary of the Missouri state border shapefile does not align with the Missouri boundary shown on topographic maps, nor other map types. This translates to GIS location points and lines slightly offset at different positions on different images or maps. To be consistent, the authors used aerial imagery provided by either MSDIS, infrared from the Missouri Resource Assessment Partnership, or Earth Imagery provided by ESRI. Glade polygons superimposed on topographic maps may otherwise overlap the borders of structures, roads or lakeshores, and appear as errors.

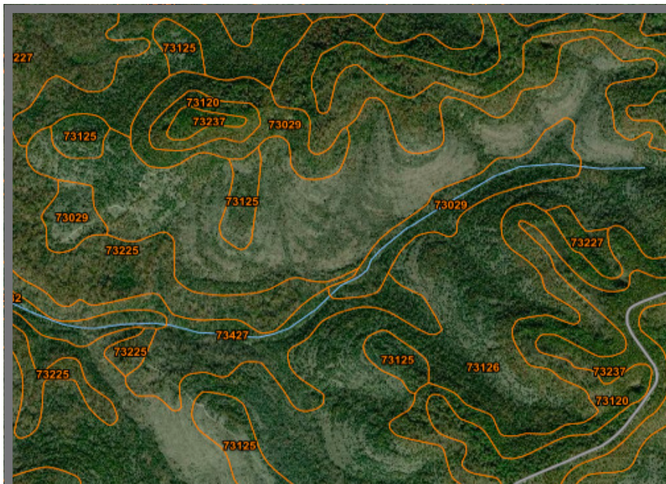

Figure 2-2. *Leaf-on topographic layer used in the glade detection and mapping process.*

Figure 2-3. *Leaf-off aerial imagery layer used in glade detection. Note clarity of glades compared to those in Figure 2-2.*

Figure 2-4. *Infrared imagery revealing Jefferson City Dolomite glades depicted in gray.*

As mapping progressed within a given characteristic landscape, patterns often emerged that helped "predict" the likelihood of additional glades, particularly if the geologic and topographic expressions remained similar. For example, igneous glades appear as amoeba-like shapes

and are often distributed along the upper to lower side slopes of St. Francois Mountain knobs and dome-shaped hills. Roubidoux Formation sandstone glades are often found when a sandstone layer intersects moderate gradient streams or upper ravines of gently dissected hills. The St. Peter Sandstone occurs as a distinct mid and upper slope bench or cliff at the same elevation with sandstone glades often occupying the top of the bench. A distinctive pattern of sandstone glades occurs within the Hermann quadrangle, and clearly correlates with a detailed spatial geologic map (Siemens, 2003). However, anomalies to the typical or predictive patterns do exist.

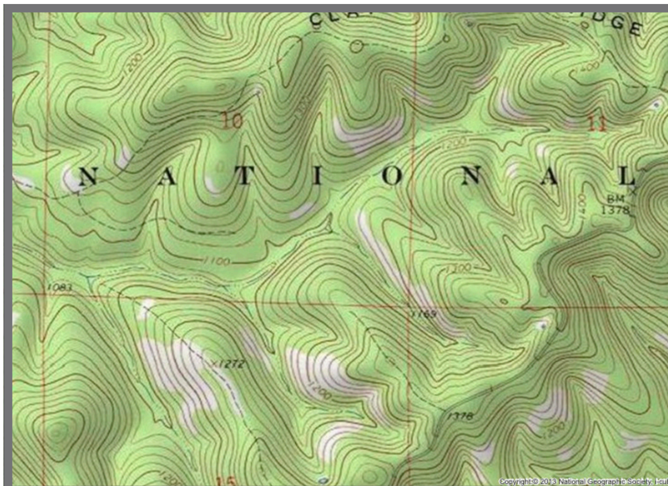

Figure 2-5. *Topographic map prior to mapping of glades. White areas denote glades.*

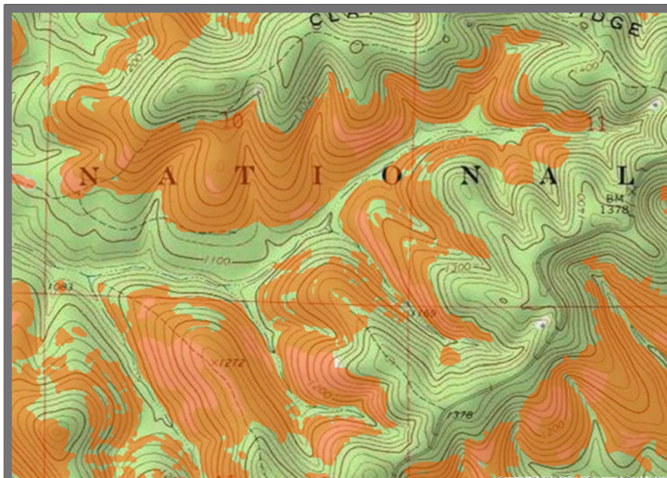

Figure 2-6. *Dolomite glades displayed over the topographic map shown in Figure 2-5.*

Interpretation of imagery varied according to glade natural community types. A history of overgrazing since European settlement has left vast areas mantled in dense thickets of red cedar, especially where dolomite and limestone glades grade into adjacent rocky woodlands on hillslopes. Determining boundaries in this situation required the combined use of infrared, leaf-off imagery and topographic interpretation. Infrared is not always reliable. False glade signatures occur on ridgetops invaded by red cedar. In general, mappers eliminated red cedar-dominated fields in floodplains, upland level plains and broad level ridgetops or gentle slopes.

Land clearing practices for pasture and cropland often excluded glades and rock outcrops, thus leaving evidence that could be detected during mapping. Repeatable patterns emerged across broad areas of pastureland. Haying or plowing often avoided rock outcrops (containing glades) leaving abrupt boundaries between hayfields and surface bedrock exposures. In aerial images these areas appear as irregularly shaped islands inhabited by red cedar, shrubs and scattered trees.

MAPPING GLADE BOUNDARIES

The polygon boundary indicates a high probability that glade characteristics are present within 10 to 50 feet of the line. This margin variation is necessary due to the complex number of irregularities along the glade border caused by the sometimes-imperceptible gradation between rocky woodlands and solid glade bedrock. Further complicating the boundary is the presence of invasive red cedar that often occupies the transition zone between glade and woodland. Some glades are poorly defined in areas transitioning from solid bedrock to thicker, often oak-dominated soils. The boundary is selected based on image interpretations that suggest the presumed bordering woodland oak tree dominance falls in the range of 10 to 30%. The greatest degree of error likely occurs along this transition. Field verification and map adjustments may be necessary to redefine this line.

Using glade mapping methodology to determine their quality is impossible, unless glades are destroyed by quarrying, buildings, reservoirs or road construction. Nearly all glades have some history of disturbance, especially livestock grazing, red cedar invasion, exotic species introduction and fire suppression. Throughout the mapping project, site visits revealed glades ranging in natural quality between having been severely damaged by surface removal of minerals, to others that exhibited remnant vegetation and a diverse native grass/forb cover occupying an intact soil profile.

EASE OF DETECTION AND PROBABILITY OF ERROR

Despite systematically canvassing more than 600 quadrangle maps using the above methodology, limitations in image quality, interference with certain vegetation cover and false glade signatures made it impossible to capture all glades. The mapping process excluded many small glade openings estimated to be less than 400 square feet because they generally are not detectible in many images, especially regions lacking leaf-off imagery. The authors found high resolution, leaf-off images to be the best for locating even the smallest glades. Leaf-on imagery (color or infrared) made it difficult to locate smaller glades. EORs noted the presence of small glades interspersed amidst a closed tree canopy that were not detected in leaf-on images. Vaughn provided detailed natural community maps depicting small glades for Don Robinson, St. Joe, Washington, Harry S Truman, and Hawn state parks. Although many are not detectible through scanning aerial imagery, this highlights the need for further refinement of the map based on field observations

and mapping. Examples of how refined mapping would benefit researchers includes the delineation of natural communities for natural area nominations, floristic surveys, the development of management or natural resource stewardship plans and glade restoration proposals.

The authors are confident they mapped igneous and chert glades to a high degree of accuracy. Owing to the limited disturbance of the mountains and hills that are underlain by igneous substrates, igneous glades are relatively easy to distinguish, especially on leaf-off images. Most igneous glades have little soil with ample lichen-covered igneous rock outcrops. These stand in stark contrast to the surrounding woodlands littered with leaves and often devoid of red cedar. However, the shallow soils on igneous knobs often contain just enough soil or weathered joints and faults to support stunted trees and shrubs. This complexity of shrub and stunted tree areas intermixed with igneous bedrock challenged the authors to tease out the glade portions of this glade-scrubland interface. As a rule, mapping occurred where glade conditions prevailed. Further, it is not possible to tease out all the small glades that occur on rock ledges of steep slopes, gorges and cliffs (e.g., Royal Gorge Natural Area). Many small bedrock openings (400 square feet on average) are widely scattered across igneous knobs and are too numerous or obscured by poor images.

The degree of error for Jefferson City glades is thought to be low excepting at transitions of dolomite glades in portions of the White River Hills where the formation intergrades with chert residuum and broken, fragmented dolomite rock outcrops and ledge exposures in adjacent woodlands. On more level topography, red cedar is often dominant and can obscure transitions between shallow bedrock and thicker, rocky soils. The authors relied on infrared imagery, and to some degree differences in soil type. The detection and delineation of glade boundaries in the narrow Ozark Border zone along the eastern flanks of the Ozark dome was relatively easy as the boundary between glade and adjacent oak-dominated woodland was much narrower and sharply contrasting as noted by Erickson et al., (1942). This may be due to the lower historical open-range grazing intensity of the region.

A few glades were mapped on tallgrass prairie. Future field work may reveal glades occur on shallow bedrock prairies (Twenty-Five Mile Prairie Natural Area, Taberville Prairie Natural Area, and La Petite Gemme Prairie), especially where characteristic glade flora occurs.

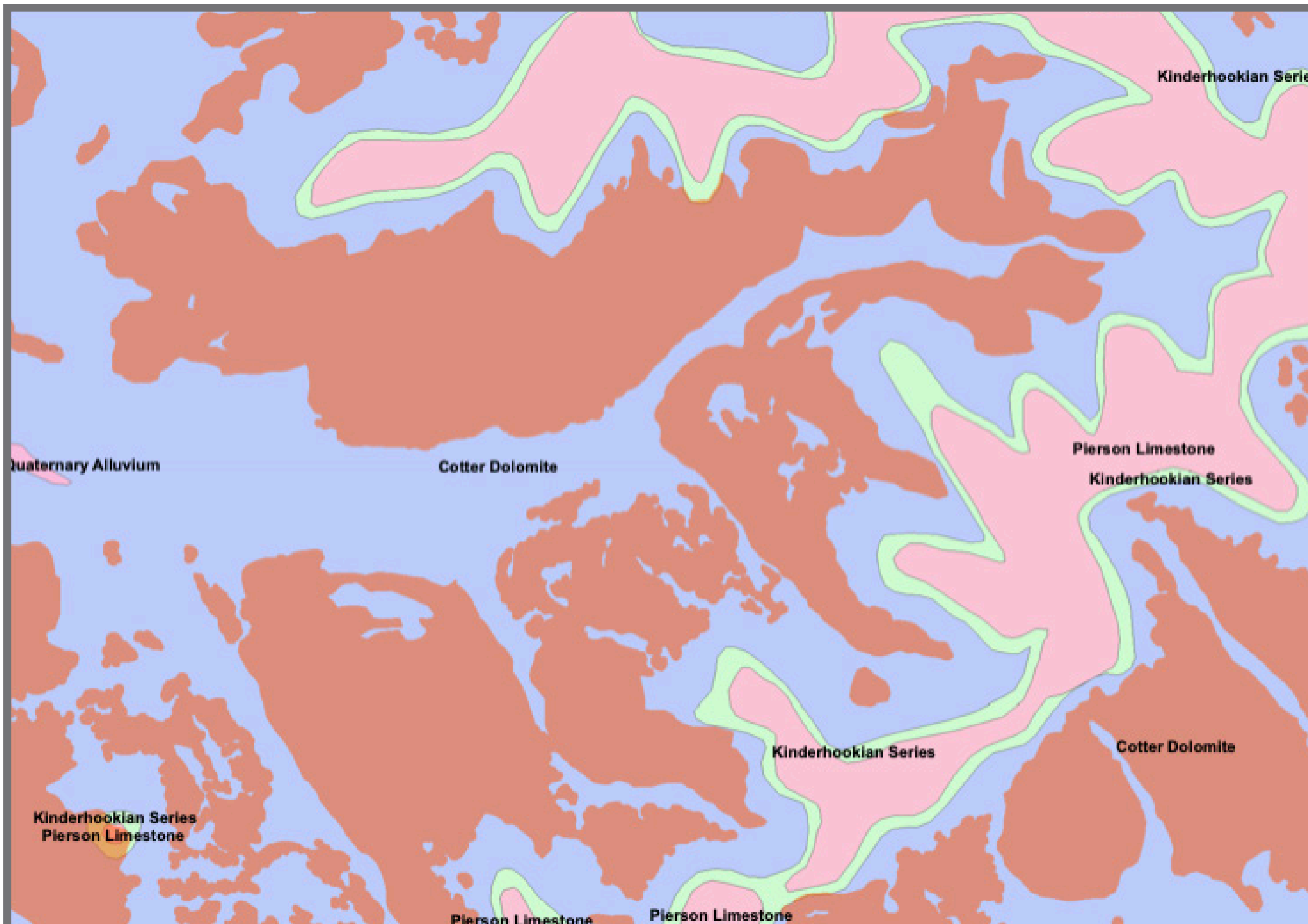

Figure 2-7. *Missouri's geologic shapefile reveals that the same dolomite glades shown in Figure 2.6 are clearly seen in the Jefferson City Dolomite Formation.*

ASSIGNMENT OF GLADE POLYGONS TO GEOLOGIC UNITS OR ROCK FORMATIONS

Approximately one year after posting the completed natural community glade shapefile on MSDIS, the authors initiated the arduous task of assigning the more than 97,000 glade polygons to one of at least 18 glade-producing geologic units or formations. While the delineating rock types seem simple (dolomite, limestone, sandstone, chert and igneous substrates), Missouri's lithology is complex and varied. Lithology is a description of the physical characteristics visible in rock outcrops, in this case bedrock and stones exposed on glades. These characteristics include color, texture, grain size, chemical composition, layering, bedding and geologic processes. In addition to intrusive and extrusive igneous rocks, the geologic formations in Missouri can also contain strata of shale, dolomite, limestone, siltstone, mudstone and sandstone. MGS published numerous regional and area bedrock geologic maps that include descriptions of various regional geological formations and series. The bedrock geology of the Fulton 30' x 60' quadrangle map (encompassing 32 7.5' topographic quadrangle maps) by Seeger and Starbuck (2012) aptly demonstrates the geologic complexity of the Upper Ozark Border Subsection. Seeger and Starbuck (2012) reference 39 technical geological mapping studies for this one area alone. Numerous structural faults, anticlines and vertical and lateral variations in lithology make determination of precise rock strata difficult. Interpreting and identifying glade patterns based on topographic and geologic mapping at 1:100,000-scale may be unreliable for certain areas and require additional field validation to correctly identify the rock formation or geologic unit.

The combination of image interpretations, correlations to topographies and geology, and other attributes revealed characteristics that improved the assignments of glade polygons to distinctive rock types. However, the most problematic application of assignment is geologic nomenclature. Fortunately, one would benefit from referring to the publication Lexicon of Stratigraphic Nomenclature in Missouri by Thompson (2001) and the Composite Stratigraphic Column for Missouri by Bridges and Mulvany (2019). Their iconic treatment of geologic nomenclature brings consistency and the understanding of relationships in correlating the geologic units used in naming glade-producing strata.

To minimize error, rock type was assigned by deciphering topography, known locations of exposed formations and EORs for glades with field notes on rock type. Field verifications were conducted in problematic areas, especially with the help of local and state geologists. This information was superimposed on Missouri's 1:500,000 generalized geologic map shapefile and more detailed 1:100,000 or 1:24,000 geologic maps, where available. As with any mapping project, there are limitations in geologic mapping related to scale. When mapped at a large enough scale (site specific) the amount of detail and accuracy can be quite high. However, at a smaller scale (1:24,000 and especially 1:500,000) details must be inferred and therefore represent relationships between units. Lithology, depositional environment and paleo (referring to relic or old) erosional surface often manifest as character and spatial variations within rock units that may not be evident in mapping at those scales. The shapefile reflects the assignment of rock type based on the most logical interpretation of the area geology, topographic patterns, soil parent materials and image signatures. Fortunately, many of Missouri's rock formations lend themselves well to identifying the prominent glade-producing rock type. While the geologic maps alone are beneficial, comparing all of these elements often led to identifying distinctive patterns associated with a geologic formation.

Chapter 3.
Geologic Characterization of Glades

The distribution and pattern of Missouri glades relate to Missouri's geologic history. Most Missouri glades are characteristic expressions of rock formations associated with the Ozark Highlands, an ancient, uplifted dome with its oldest volcanic core centered in the St. Francois Mountains in east-central Missouri. Radiating outward across the state in a bulls-eye pattern from the St. Francois Mountains are concentric rings of progressively younger sedimentary rock formations. Beginning at its center, the oldest to youngest sedimentary rocks are of Cambrian, Ordovician, Silurian, Devonian, Mississippian and Pennsylvanian ages.

Descriptions in Chapter 4 for Missouri's 18 glade-producing geologic formations are organized by following the age chronology from the oldest rocks of the St. Francois Mountains core to Pennsylvanian series rocks on the outer fringes of the Ozark Plateau. The interactive geologic map of Missouri (link follows) provides an excellent tool from which to understand the distribution of glades, especially the cross-section legend at the bottom of the map, and geologic column to the left.

- List of geologic units – mrdata.usgs.gov/geology/state/geog-units.html
- County list of geologic units – mrdata.usgs.gov/geology/state/sgmc-unit.php?unit=MOMo;0
- Link to interactive geologic maps for Missouri – dnr.mo.gov
- Updated geologic data layers for Missouri, including 1:24,000, 1:100,000 and 1:500,000 scale geologic mapping – dnr.mo.gov/land-geology/maps-data-research/geosciences-technical-resource-assessment-tool-geostrat

Glade-producing geologic formation	Terrestrial natural communities of Missouri	International ecological classification standard
St. Francois Mountains Volcanic Supergroup St. Francois Mountains Intrusive Suite	Igneous glade natural community	Ozark igneous glade
Lamotte Sandstone	Sandstone glade natural community	Ozark Sandstone Glade
Elvins and Bonneterre dolomite	Dolomite glade natural community	Ozark Dolomite Glade
Eminence and Potosi dolomites (Eminence Dolomite and Potosi Dolomite)	Dolomite glade natural community	Ozark Dolomite Glade
Gasconade Dolomite	Dolomite glade natural community	Ozark Dolomite Glade
Roubidoux Formation	Sandstone glade natural community	Ozark Sandstone Glade
Jefferson City Dolomite	Dolomite glade natural community	Ozark Dolomite Glade Ozark Ashe's Juniper Glade/Woodland
St. Peter Sandstone	Sandstone glade natural community	Ozark Sandstone Glade
Joachim Dolomite	Sandstone glade natural community	Ozark Sandstone Glade
Plattin Limestone	Limestone glade natural community	Ozark Limestone Glade
Compton and Pierson limestones (Compton Limestone, Pierson Limestone)	Limestone glade natural community	Ozark Limestone Glade
Grand Falls Chert	Chert glade natural community	Ozark Chert Glade
Burlington and Keokuk limestones (Keokuk Limestone, Burlington Limestone)	Limestone glade natural community	Ozark Limestone Glade
Channel sandstones	Sandstone glade natural community	Ozark Sandstone Glade
Bethany Falls Limestone Member of the Swope Formation within the Kansas City Group	Limestone glade natural community	Not included
Miscellaneous shales	Not included	Central Shale Glade
Miscellaneous Meramecian Limestone	Limestone glade natural community	Ozark Limestone Glade

Table 3-1. *Crosswalk of natural community classification assignments by geologic unit. A comparison between terrestrial natural communities of Missouri (Nelson, 2010) and International Ecological Classification Standard (NatureServe, 2009).*

Chapter 4. Overview: The Glade-Producing Rock Formations

The descriptions of glade-producing rock formations in this report are organized chronologically beginning with the oldest formations of the Mesoproterozoic-age (Precambrian-age) units in the St. Francois Mountains and emanating outward through the Ozarks and Osage Plains. Table 4-1 highlights the ages of the glade-producing unit and taxonomic names of the rock formations.

Physiographic regions of Missouri are shown in Figure 4-1; the Missouri Geologic Map in Figure 4-2 depicts relative locations of the bedrock units underlying those regions. The stratigraphic column (Fig. 4-3) illustrates the ages of the documented glade-producing bedrock units in this report and highlights their relative stratigraphic location. The color schema of Figures 4-2 and 4-3 are consistent.

The physiographic regions of the U.S. originally were defined by Fenneman (1928), and later highlighted through a series of maps by Fenneman and Johnson (1946). Figure 4-1, a generalized version of the Physiographic Regions of Missouri is available as a fact sheet from MGS at dnr.mo.gov. The 1:500,000-scale Geologic Map of Missouri shown in Figure 4-2, along with other geologic maps of the state are available online through the Missouri Geologic Map Index at dnr.mo.gov. The Composite Stratigraphic Column for Missouri (Fig. 4-3) was altered for simplification and use within this report to highlight only glade-producing bedrock formation. A detailed version of the original stratigraphic column produced by Bridges and Mulvany (2018) is available at dnr.mo.gov. Figure 4-4 refers to the 31 ecological subsections delineated within Missouri's four ecological sections described in the Atlas of Missouri Ecoregions by Nigh and Schroeder (2002). The map serves as an ecological framework for identifying, describing, and mapping units of land possessing similar physical and biological characteristics. The glade unit descriptions herein often reference the Atlas as a means of correlating glade patterns and distribution with ecological subsection delineations.

Geologic formations become progressively younger outward from the center of the Ozark dome (St. Francois Mountains) with bedrock forming broad elliptical rings (Fig. 4-2), each 10 to 60 miles wide. These rings are widest and longest to the west toward the Springfield Plateau. The dip steepens and the rings narrow (5-10 miles wide) toward the east and northeast along the Ozark Border transition into the Illinois Basin. While extensive in the basin, the Pennsylvanian-age bedrock units are absent in that area of the state. Bordering the outermost Ordovician-age ring to the north and west are Mississippian- and Pennsylvanian-age formations, which gently dip under the Osage Plains and Dissected Till Plains of western and northern Missouri. The number and density of glades are greatly reduced in these areas as the bedrock units are buried by the deep mantle of loess, glacial till and alluvial parent material.

Age/Geologic period	Glade-producing geologic formation
Mesoproterozoic (Precambrian)	St. Francois Mountains Volcanic Supergroup St. Francois Mountains Intrusive Suite
Middle Cambrian	Lamotte Sandstone
Middle/Upper Cambrian	Elvins and Bonneterre
Upper Cambrian	Eminence and Potosi Dolomite
Lower Ordovician – Ibexian	Gasconade Dolomite Roubidoux Formation Jefferson City Dolomite
Middle Ordovician – Whiterockian	St. Peter Sandstone
Ordovician – Whiterockian/Mohawkian	Joachim Dolomite
Upper Ordovician – Mohawkian	Plattin Limestone
Mississippian – Kinderhookian/Osagean	Compton and Pierson limestone
Mississippian – Osagean	Grand Falls Chert Burlington and Keokuk limestone
Mississippian – Meramecian	Warsaw Formation Salem Formation St. Louis Limestone
Pennsylvanian – Various	Channel sandstones
Pennsylvanian – Missourian	Bethany Falls Limestone Member of the Swope Formation within the Kansas City Group
Potential glade-producing shale formations of various age	
Devonian through Pennsylvanian	Chattanooga Shale (Devonian) Hannibal Shale (Mississippian) Various cyclothems (Pennsylvanian)

Table 4-1. *Geologic Time Periods and Primary Glade-Producing Geologic Formations (oldest to youngest geologic periods).*

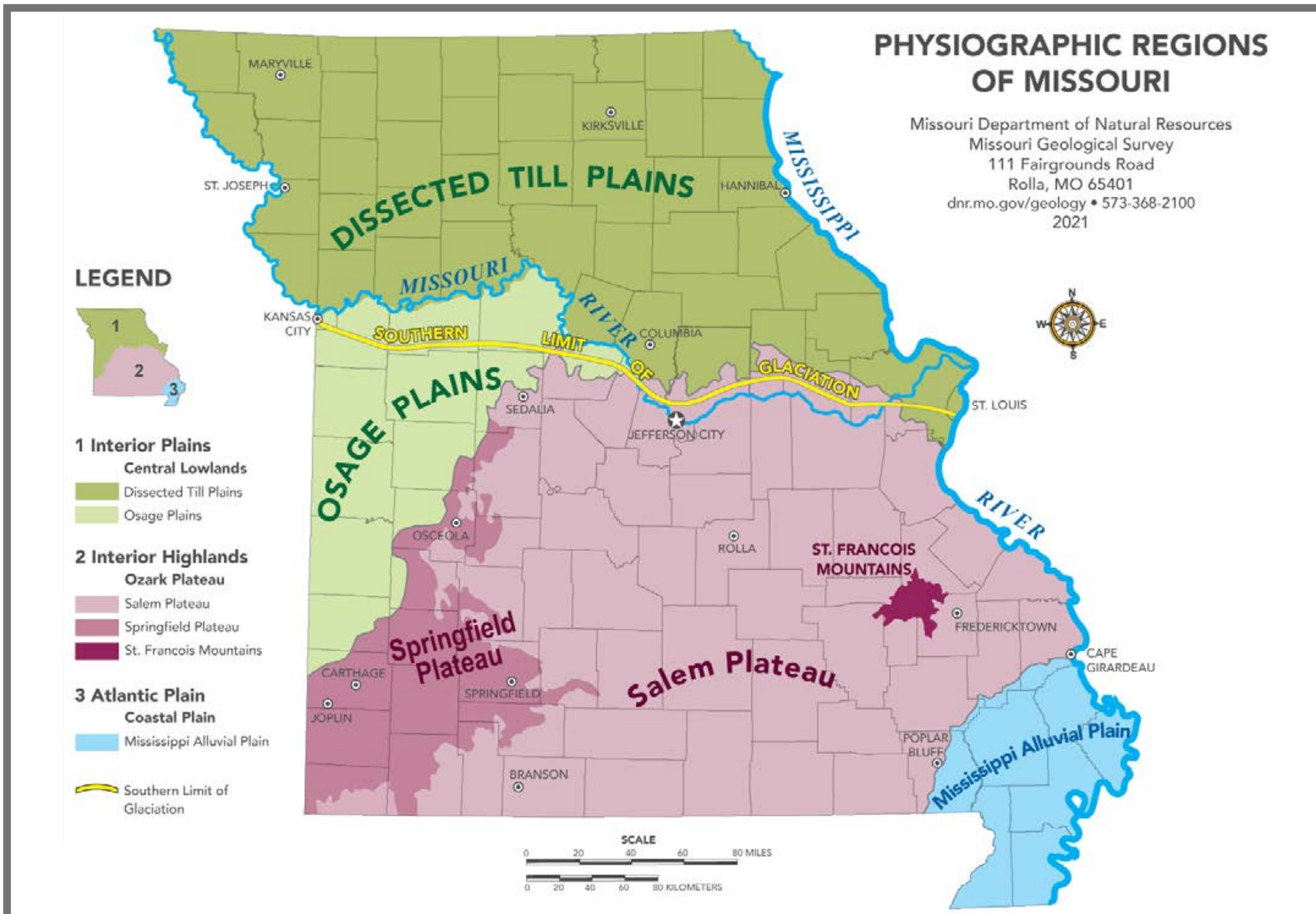

Figure 4-1. *Physiographic region map of Missouri. Source: Missouri Department of Natural Resources after Fenneman and Johnson, 1946. Most Missouri glades occur within the Ozark Plateau.*

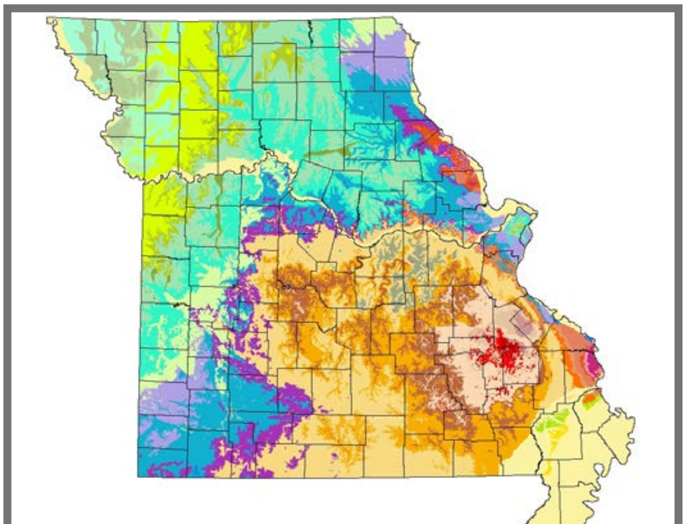

Figure 4-2. *Generalized geologic map of Missouri after Starbuck, 2017.*

Number per 12 sq. mile	Distance apart	Spacing density
> 120	100 – 500 feet	Dense
50 – 120	500 – 1,000 feet	Widespread
10 – 50	1,000 – 5,000 feet	Scattered
< 10		Isolated

Table 4-2. *Glade density table.*

The glade geologic unit chapters are organized according to the following attributes:

a. Geologic unit name or formation: the word "glade" in each chapter refers to the chapter's respective geologic unit glade type.

b. Numerical statistics: table of numerical values (number, acres, perimeter, area square footage, minimum/maximum, and means) is generated from the attribute table for each rock formation.

c. The rock type (as determined in Chapter 2) is assigned to each of the five glade natural communities described in The Terrestrial Natural Communities of Missouri (Nelson, 2010).

d. Missouri distribution according to the General Geologic Map of Missouri, ecological map units (Table 3-1), river systems and counties.

e. Topographic relationships: elevation, roughness, landscape position, slope.

f. Aspect: (Fig. 4-5, sample radial aspect chart).

g. Size, shapes and patterns: glades isolated (insular) or dominant on the landscape (matrix).

h. Distribution density (Table 4-2)

i. Lithology: bedrock characterization such as: texture, porosity, water-holding capacity and formation variations.

j. Public land locations and future protection opportunities: A future gap analysis and inventories should consider implications as discussed in Cartwright and Wolfe (2016) with emphasis given to insular glade types surrounded by human developments.

The Burlington and Keokuk limestone glades sample radial aspect chart contains polygons that illustrate select concentrations of each glade formation type across different areas within their respective statewide distribution. Unless otherwise stated, a 12-square-mile area is centered over several (generally three) concentrations of glades. Each is assigned an aspect (or aspects if the glade is complex and faces different directions). Each axis represents the primary facing direction, or aspect, of the glade. The Rocky Barrens glade complex indicates glades face all aspects because all of the polygon points occur away from the center (point 0). The largest number of glades in Rocky Barrens face west and southeast. The Warsaw polygon of 40 glades reflects a dominant southwest-facing aspect. No glades face northwest, north, northeast or east (note those points occur at the center at zero) in the smallest Jamestown polygon. Polygon sizes vary depending on the total number and area of glades assessed. Glades with little to no aspect (less than 5%) are not included in the count but are discussed for each figure when significant.

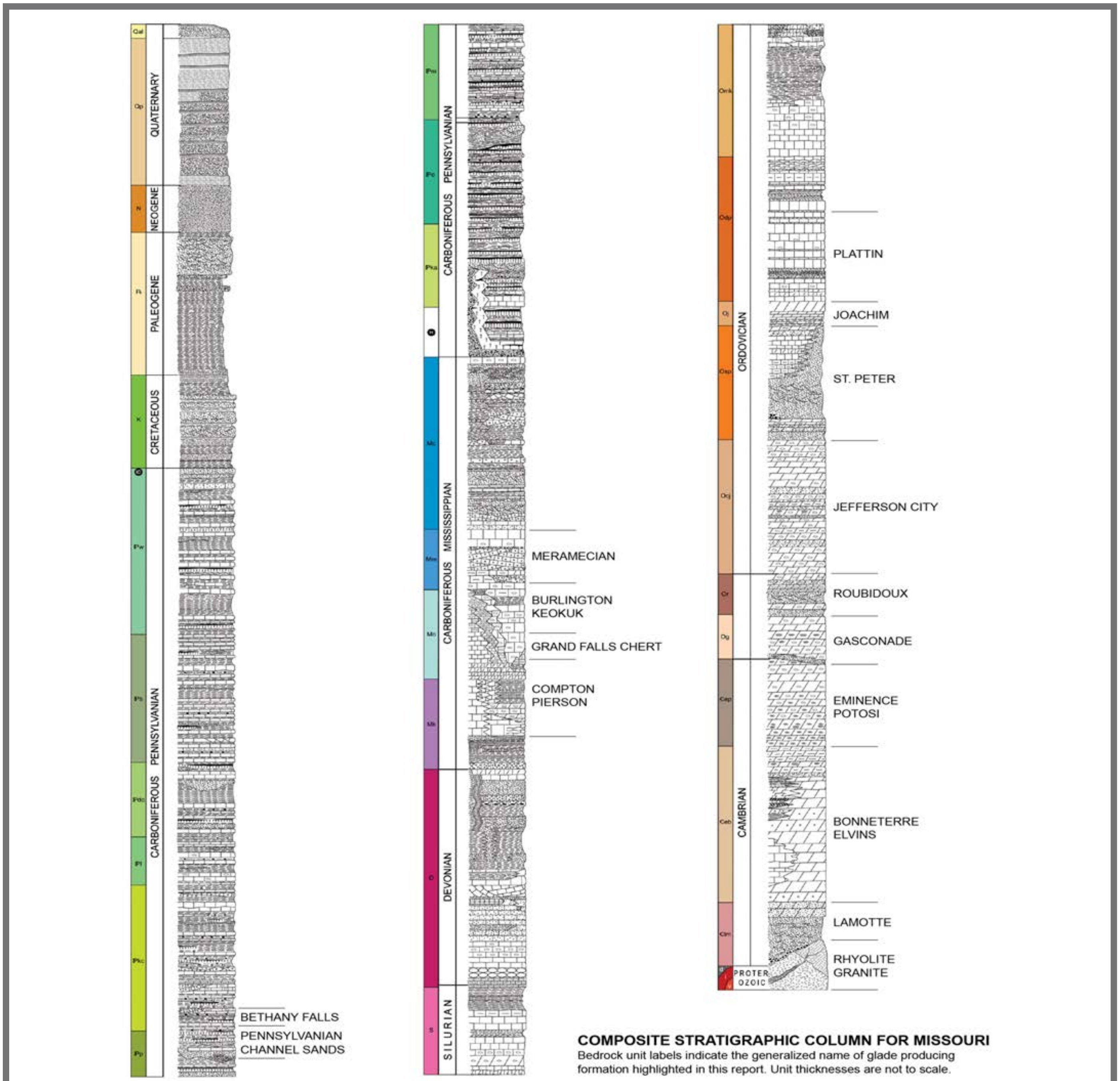

Figure 4-3. *Stratigraphic column highlighting the glade-producing formations after Bridges and Mulvany (2019). The color scheme matches those of the Generalized Geologic Map in Figure 4-2.*

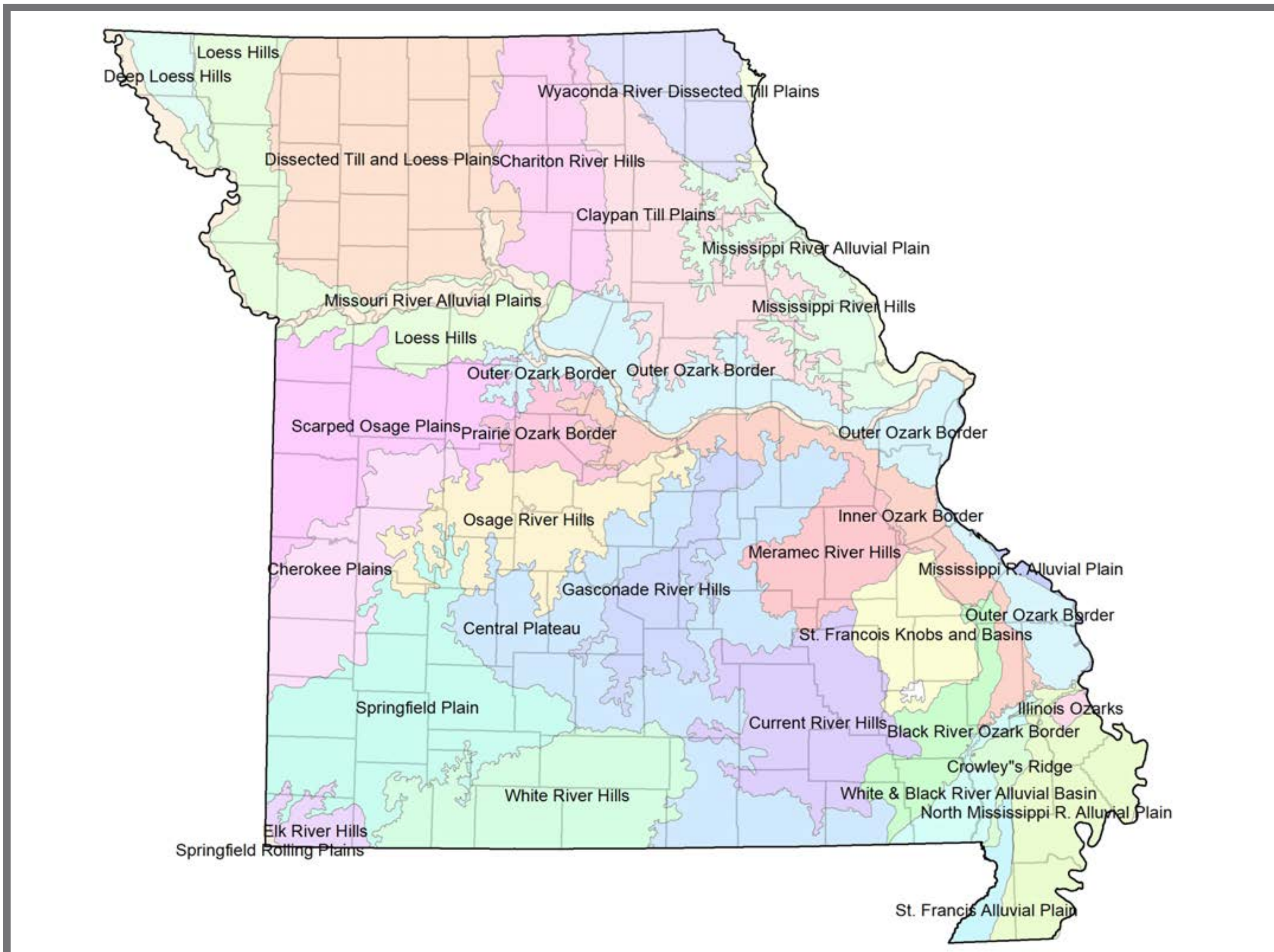

Figure 4-4. *Map highlighting the primary names of ecological subsections of Missouri, after Nigh and Schroeder, 2002.*

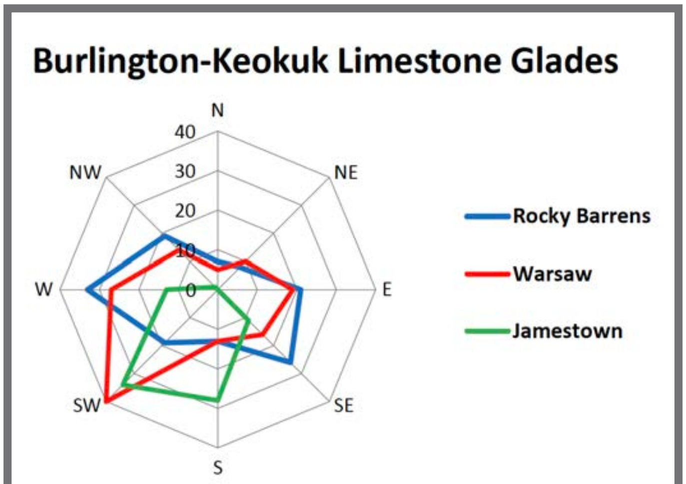

Figure 4-5. *Sample radial aspect chart.*

Chapter 5. Mesoproterozoic-Age Glade-Producing Formations

Figure 5-1. *Rhyolite (igneous extrusive) glade in Taum Sauk Mountain State Park, Iron County. MoDNR photo by Ken McCarty.*

More than 12,400 igneous glades totaling 11,832 acres were mapped across the St. Francois Mountains, and in the Current River Hills Ecological Subsection of the Ozark Highlands (Fig. 5-2). Numerous geologic studies attest to the ancient and complex geological history of volcanism across this region. This is largely due to the complexity and discontinuity of the volcanism across the landscape followed by erosion, uplift and faulting spanning a billion years. Many shapes and patterns result from the complexities of uplifting, faulting, exposure of former magma chambers, rebuilding of lava hills along collapsed caldera fault lines, erosion, and pyroclastic flows-all repeated through millennia. Berry (1976), Pratt and others (1979), and Sides et al. (1981) delineated igneous geologic units of the St. Francois Mountains. Thompson (2001) 20 years later referred to the St. Francois Mountains Volcanic Supergroup and the St. Francois Mountains Intrusive Suite (Thompson, 2001) as "terranes." The volcanic group includes rhyolitic ash-flow tuffs, lava flows, bedded tuffs, basalt and trachytes. The term, intrusive refers to magma that crystallizes beneath the earth's surface then is later exposed at the surface through ancient erosional cycles. Most, but not all intrusive rocks in the St. Francois Mountains are granites. Granites are generally medium to coarse crystalline as seen at Elephant Rocks State Park (Iron County). Geologists have described many types of granite ranging in composition from low- to high-silica including the Graniteville, Knoblick, Slabtown, Silvermine, Butler Hill, Breadtray and Munger lithologic units.

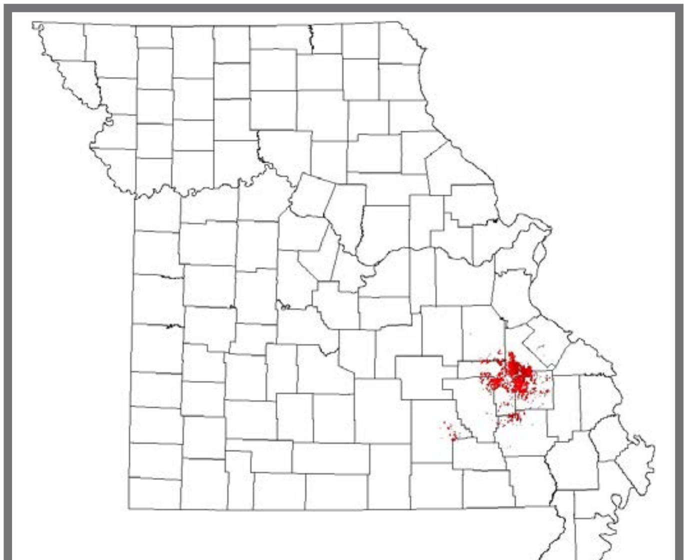

Figure 5-2. *Outcrop pattern of Mesoproterozoic-age (Precambrian) rock units in the St. Francois Mountains of eastern Missouri.*

In 2018, Lori and Seeger described at least 88 igneous units, many with both formal and informal names. Their shapefile resulted in the map (Fig. 5-3) that displays these numerous units.

Ecological classification treatments (Nelson, 2010) describe the Mesoproterozoic-age (Precambrian) glade-producing substrates as igneous glades. From an ecological perspective, botanists and ecologists can generally divide most of the mapped glades into two primary igneous types with the understanding that many varia-

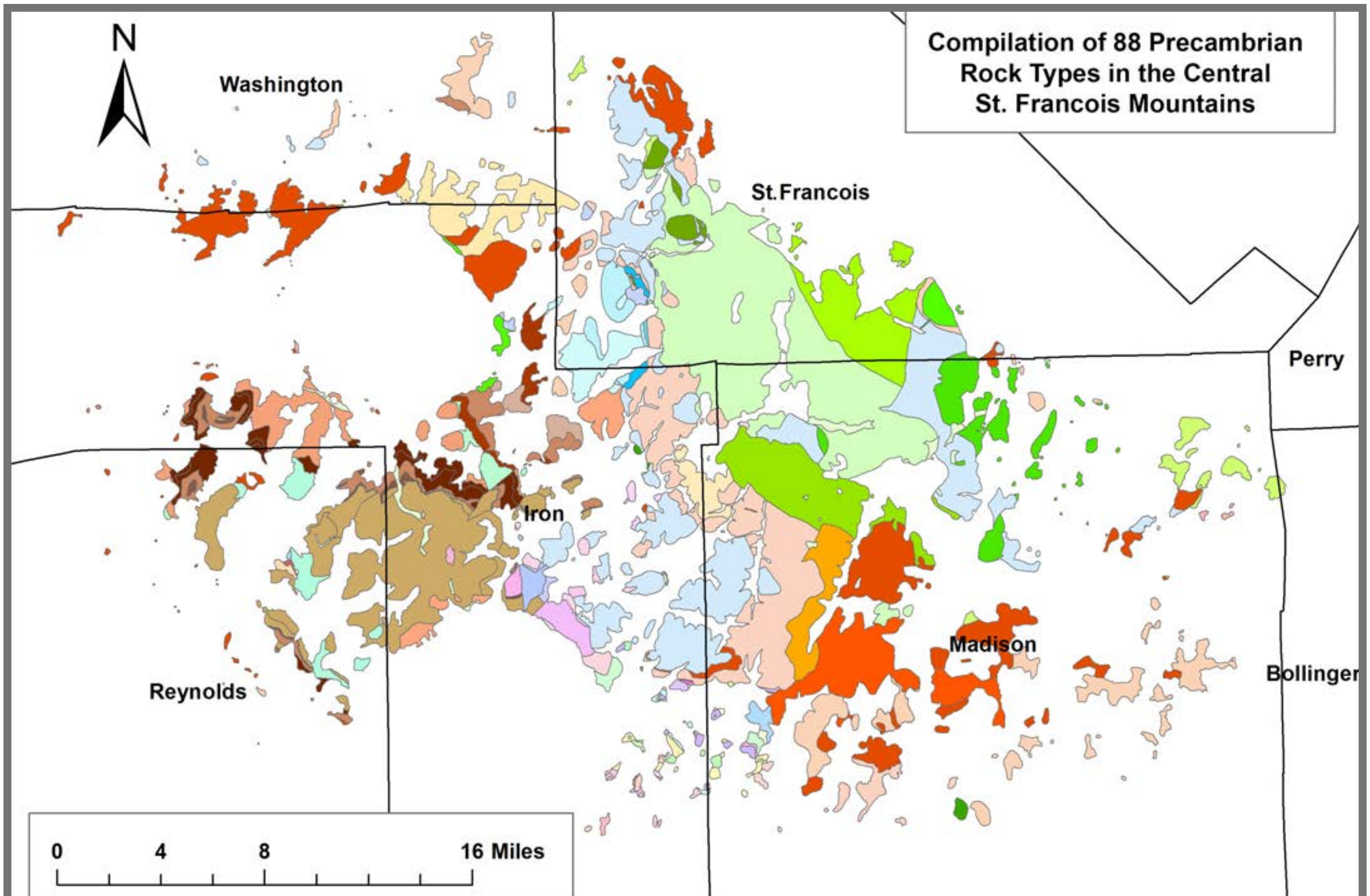

Figure 5-3. *Compilation Map of 88 igneous units in the central St. Francois Mountains (Lori and Seeger, 2018).*

tions occur among them: intrusive granite glades and extrusive rhyolite glades (inclusive of other volcanic geologic units). Future field examinations may result in further divisions of igneous types based on differences in plant communities or species distributions.

In general, the following range of variations occurs that may influence differences in plant distributions:

1. Granitic glades (Fig. 5-12) often form rounded massive outcrops, which contain numerous joint fractures. These fractures usually fill with large disintegrated granitic materials consisting of primarily quartz and feldspar minerals and support a variety of shrubs, stunted trees and herbs. Their presence often differentiates granite from rhyolite and other types if aerial images are clear. In situ weathering along fractures often leads to the rounded nature of granitic terranes. Granite glades often contain large in situ weathered boulders or rock towers (as much as 15 feet tall) called tors, such as those observables at Elephant Rocks State Park (Iron County). An undulating surface on granite outcrops can be produced by pressure exfoliation and accentuated by freeze/thaw or current climatic conditions. This weathering often results in solution pools and enlarged fractures and can help to support the variety of shrubs, stunted trees and herbs mentioned previously. The feldspar minerals present in granites slowly weather chemically to produce kaolinite and a gravelly byproduct called grus consisting of the remaining quartz and feldspar minerals.

2. Extrusive rocks (rhyolite, ash-flow tuff, pyroclastic rocks) due to their small crystalline nature weather extremely slowly. Variations in cooling rates, mineral content and origin of placement of igneous extrusive rocks can result in differences observed in jointing patterns. Where cut by streams or storm water runoff, plunge pools are common. On steep slopes, multiple series of jagged ledges and cliffs can occur, even at high elevations such as Devil's Wall and Royal Gorge (Iron County). Due to their low permeability and mineral composition, permanent acid seeps can occur on glades situated below thicker soil woodlands.

3. Larger streams and rivers coursing between igneous mountains and hills often scour exposed igneous bedrock along streambanks. This results in the development of "scour" glades along higher rocky edges of the waterway. These scours, while maintained by periodic flash flooding, are droughty enough to support glade flora. An example of a scour glade occurs below the shut-ins at Johnson's Shut-Ins State Park.

GRANITE GLADES – Geologic units primarily igneous intrusive glades.
RHYOLITE GLADES – Geologic units primarily igneous extrusive glades.

Number of glades	3,220	9,183
Minimum size	0.04 acre	0.02 acre
Maximum size	31 acres	67 acres
Total acreage (sum)	2,421 acres	9,410 acres
Mean size	0.8 acre	1.0 acre
Maximum perimeter	3.5 miles	6.3 miles
Total perimeter	552 miles	1,913 miles
Mean perimeter	1.4 miles	0.2 mile
Pattern density	Dense to widespread in clusters associated with igneous mountain knobs.	
Classification – Terrestrial Natural Communities of Missouri (Nelson, 2010)	Igneous glade natural community	
Classification – International Ecological Classification Standard (Nature Serve, 2009)	Ozark Igneous Glade	

Table 5-1. *Statistical summary of Mesoproterozoic-age (Precambrian-age) igneous glades. Extrusive includes other volcanic materials.*

MISSOURI DISTRIBUTION

The St. Francois Mountains are high, broad knobs, remnants of ancient volcanoes and exposed granitic plutons covering 5,000 square miles centered in northeast Iron County and crossing over into adjacent Washington, St. Francois, Madison and Reynolds counties. The actual extent of igneous exposures is approximately 560 square miles. Additional localized areas of igneous rocks occur in portions of Shannon and Carter counties along the Current River and in several locations in Wayne and southern Iron counties.

Concentrations of densely packed and complex amoeboid-shaped glades are common on most igneous mountains. Stunted trees or islands/groupings of trees are scattered within and surrounding most glades. Numerous small glades or rock outcrops are widely distributed throughout woodlands. Some shape and pattern anomalies include the spiraling concentric ring pattern of glades on Bell Mountain (Iron County), which includes the largest 67-acre continuous igneous glade atop a 1-mile elongated cliff escarpment. To the northeast, Hughes Mountain (Washington County) contains glades of exposed igneous rocks with columnar jointing originating from felsitic rhyolitic ash flows.

Figure 5-4. *Igneous glades scattered over broad knobs in St. Francois Mountains. St. Francois Mountains Natural Area, Taum Sauk Mountain State Park, Iron and Reynolds counties.*

TOPOGRAPHIC RELATIONSHIP TO DISTRIBUTION PATTERNS

The largest region of granite glades occurs 8 miles south and west of a line trending from Pilot Knob (Iron County) to Doe Run (Madison County). Nigh and Schroeder (2002) did not apply "glade" to the name of the Roselle Oak Woodland Upland Igneous Plain. However, two-thirds of the mapped 3,100 intrusive glades in the St. Francois Mountains occur in this area. Elevation ranges from 750 to 1,300 feet. Patterns reveal granitic glades occur on all aspects with slopes of 5-25%. Igneous extrusive rhyolites, ash flows, and other volcanic rock types occur at elevations between 700 to 1700 feet. The highest elevation glade (1,740 feet) is located near the top of Taum Sauk Mountain (Iron County). This prominent rhyolite glade offers scenic, expansive vistas from an interpretive observation deck on top of the mountain.

Intrusive and extrusive rock are erosion resistant, especially rhyolites and ash-tuff flows. There is no better example of this erosional resistance than the geologic phenomenon known as "a shut-in." The most popular example is Johnson's Shut-Ins State Park (Reynolds County). Flowing through a gorge of rhyolite canyon walls, the East Fork of the Black River has gradually carved through the resistant rhyolite bedrock for thousands of years. Soil formation on exposed extrusive rhyolite bedrock is slow and difficult due to the periodic scouring from heavy rain events, steep slopes and the extremely erosion resistance of the rock. Many of the high St. Francois Mountains are eroded remnants of caldera systems. Several of these remnant igneous hills are rhyolitic, highly welded ash flow and fall tuffs, lava flows and pyroclastics that erupted in association with caldera collapse. Many of these units are solid, impermeable extrusive masses that may be a few thousand feet thick, and often have glades. Prolonged summer droughts characteristically leave late summer tree canopy brownouts or die offs across the knobs, attesting to the delicate balance of groundwater in enough supply to sustain trees.

In general, the steeper the slope on the flanks of igneous mountains, the greater the likelihood that weather-resistant glades will occur. Igneous mountains are resistant to rainwater infiltration, thus heavy precipitation cascades down moderate to steep slopes. The extreme xeric conditions of granite glades do not readily give way to invading woody vegetation. Glades occupy steep backslope flanks of most prominent mountains, particularly the steeper, lower-half regardless of aspect. When encircling the larger mountains (Fig. 5-7), the result reveals the location and extent of nearly all the mountain knobs, each giving the appearance of irregular fairy rings, or circles of glades spanning several miles. Connecting the often densely compressed "dots" of these glades coincides with the lower elevation of igneous mountains, thus revealing their topographic locations. It also indicates glades occur on all aspects. The gaps within the circles (many having scattered glades) indicate the presence of thicker, wooded soils. Many mountains have broad tops occupied by flatwoods and dry oak woodlands.

Other variations of glade patterns and locations include those found along streams adjacent to shut-ins, scour channels, and atop extensive massive granite extrusions and bluff tops.

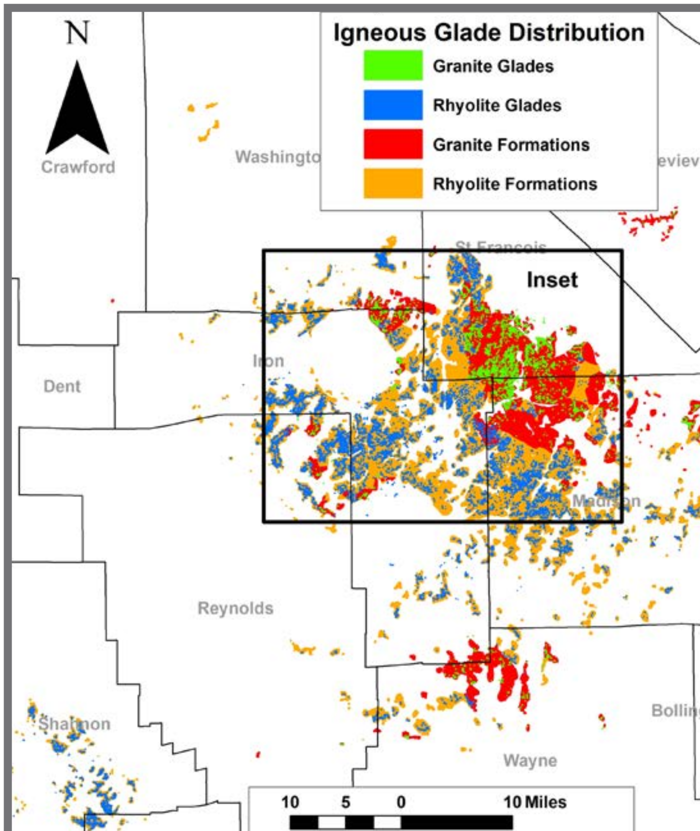

Figure 5-5. *Distribution of igneous glades in east-central Missouri superimposed on igneous formations. Note inset.*

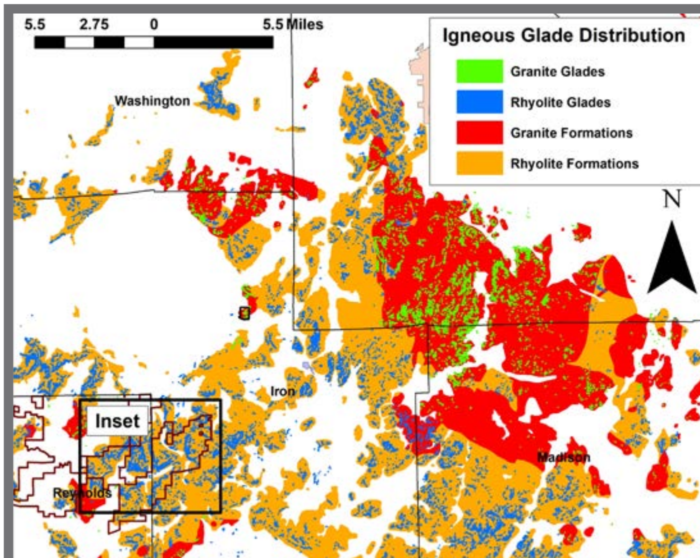

Figure 5-6. *Close-up of inset in Figure 5-5. Figure 5-7 depicts topographic relationship in the inset lower left above.*

LITHOLOGY, SHAPE AND SIZE

Numerous geologic reports and studies of the St. Francois Mountains point to the complexity of their volcanic history and lithology. At least five apparent calderas (Day et al., 2016) are inferred by the presence of thick rhyolitic ash flow tuffs, ring faults, ring intrusives, breccias, and pyroclastic rocks. Exposed plutons of ancient magma chambers occur as exposures of granites, bimodal gabbro and porphyry (Bickford et al., 1981). Add to these numerous studies of complex rock chemistry, particularly the work of Connor and Ebens (1980) differentiating chemical analysis of granite (intrusive) and rhyolite (extrusive) rock.

In Figure 5-10, glade aspect is essentially in all directions for the estimated 120 glades on Hughes Mountain in northeast Washington County with 14 glades on nearly level aspect. In a 9-square-mile area centered on the crest of Proffit Mountain in Iron and Reynolds counties, 217 igneous extrusive glades occur on all aspects but are prominent on west and southeast exposures. Twenty-seven glades occur on essentially level aspects. This difference is attributed to the circular shape of Hughes Mountain while Proffit Mountain is well-elongated to the north and south with much longer flanks for glade formation on east and west slopes.

In Figure 5-11, roughly 330 igneous intrusive glades occupy a 9-square-mile area located south of Buck Mountain in St. Francois County. The area is dominated by igneous knobs averaging 500 to 600 feet of elevation change. Two-thirds of this number face west, south and southeast to east. In contrast, a second 9-square-mile area of 219 concentrated intrusive glades occurs on the flanks of flattened igneous hills and plains centered on Klondike Hill, 4 miles northeast of Buck Mountain in St. Francois County. Elevations range from 750 to 1,000 feet. Some 190 face east and west from a point encompassing 12 square miles on Proffit Mountain in Iron County. Over 105 glades (12%) occur on nearly level terrain with many on gentle slopes.

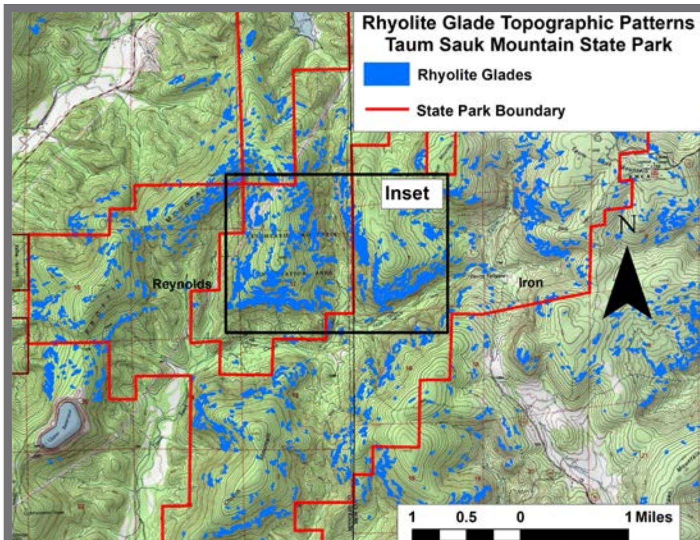

Figure 5-7. *Close up of inset in Figure 5-6 depicting igneous glade distribution in relationship to topography. Rhyolite glades are most densely concentrated on steeper mid to upper flanks of mountain domes. Note: Inset is expanded in Figure 5-8.*

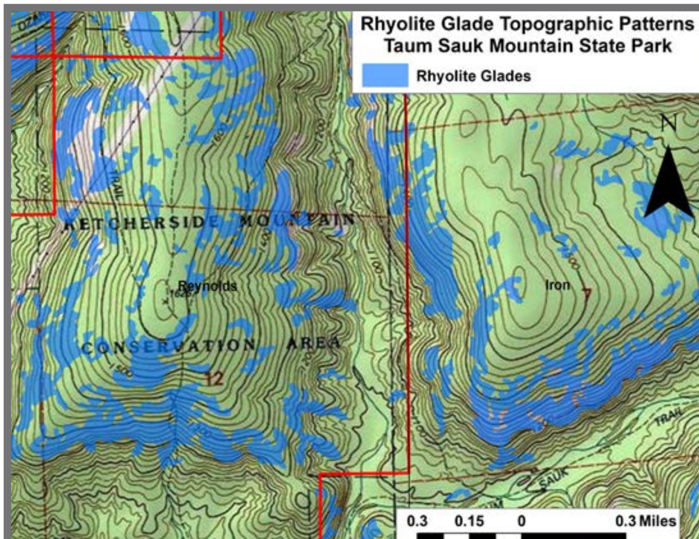

Figure 5-8. *Close up of rhyolite glades distributed across two igneous knobs in the St. Francois Mountains Natural Area, Taum Sauk Mountain State Park (Iron and Reynolds counties).*

Figure 5-9. *Rhyolite (left) and granite (right). The rhyolite has an aphanitic/porphyritic texture (finely crystalline groundmass with only a few larger phenocrysts that can be seen with the naked eye). The granite has phaneritic texture with crystals of quartz and feldspar large enough to be seen with the naked eye. MoDNR photo by Pierce.*

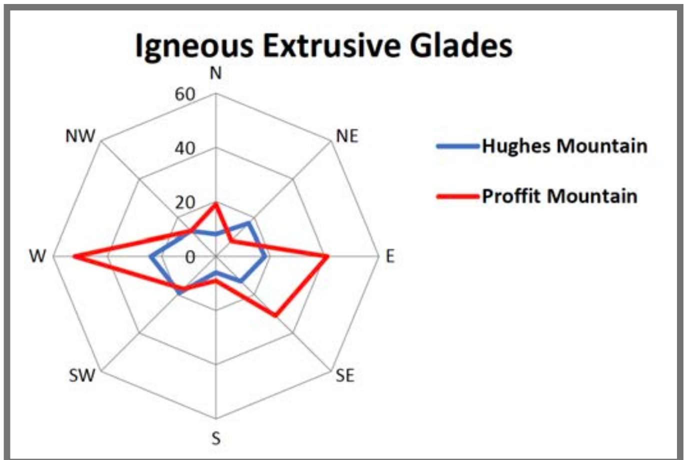

Figure 5-10. *Igneous extrusive glade aspect chart.*

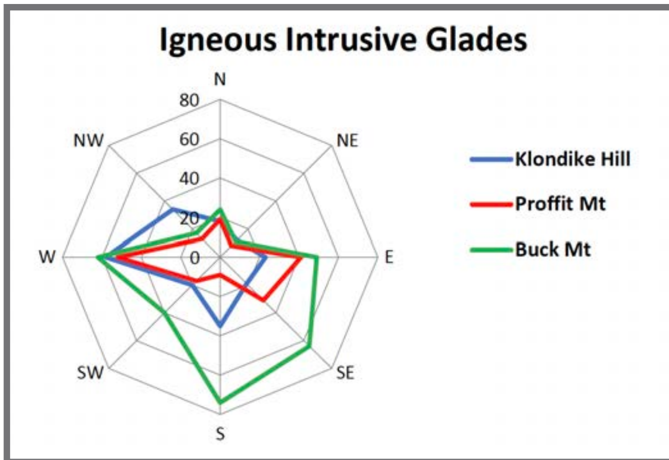

Figure 5-11. *Igneous intrusive glade aspect chart.*

Analysis of the 50 largest glades in each igneous category indicates the largest occur across extrusive rock types. At 67 acres, the largest granite glade on Bell Mountain (St. Francois County) is a 1-mile-long ascending glade atop a steep inaccessible cliff ledge. The next largest is the 51-acre glade on Weimer Hill in Taum Sauk Mountain State Park (Iron County). Floristically, this glade is considered the highest quality and most diverse in the St. Francois Mountains. The largest rhyolite glade (31 acres) occurs on the west flank of Buford Mountain (Iron County).

PUBLIC LAND LOCATIONS AND FUTURE PROTECTION OPPORTUNITIES

Fortunately, owing to the isolation and character of the St. Francois Mountains, many igneous glades are protected in matrices of managed woodlands on public lands. Their highest and best use is recreation, wilderness, hiking, hunting, scenery and nature study. Thousands of acres are in public ownership, and actively managed for restoration. Premiere showcase examples occur in Johnson's Shut-Ins (Reynolds County) and Taum Sauk Mountain (Iron County) state parks. Collectively, at over 17,000 acres, these state parks protect 727 igneous glades totaling 1,124 acres. Other important areas include Ketcherside Mountain (Reynolds County), Buford Mountain (Iron County), Hughes Mountain (Washington County) and Peck Ranch (Shannon County) conservation areas as well as the Ozark National Scenic Riverways, and MTNF.

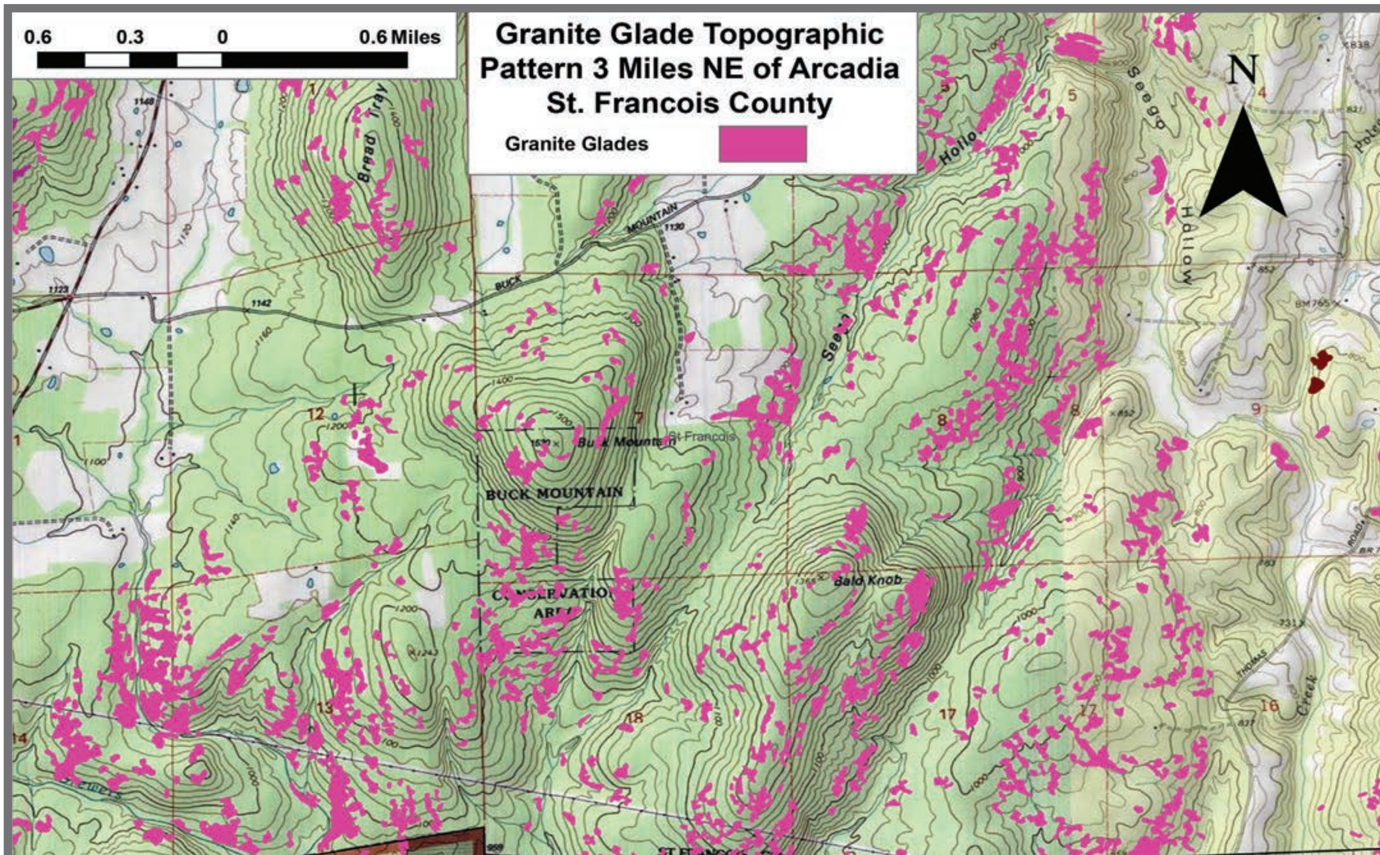

Figure 5-12. *Distribution pattern of granite glades over knobs in St. Francois and Madison counties near Arcadia in Iron County.*

Chapter 6. Cambrian-Age Glade-Producing Formations

MIDDLE CAMBRIAN-AGE GLADE-PRODUCING FORMATIONS

LAMOTTE SANDSTONE GLADES

Number of glades	838
Minimum size	0.03 acre
Maximum size	10.6 acres
Total acreage (sum)	460 acres
Mean size	0.6 acre
Maximum perimeter	1.5 miles
Total perimeter	125 miles
Mean perimeter	0.1 mile
Pattern density	Locally dense, widespread to scattered in several clusters
Classification – Terrestrial Natural Communities of Missouri (Nelson, 2010)	Sandstone glade natural community
Classification – International Ecological Classification Standard (Nature Serve, 2009)	Ozark Sandstone Glade

Table 6-1. *Statistical Summary of Lamotte Sandstone glades.*

MISSOURI DISTRIBUTION

Sandstone glades are localized in a small 25-square-mile area encompassing Ste. Genevieve, Madison and St. Francois counties. Mapping uncovered two primary clusters, each nearly equally sharing half of 800 glades. The first is situated entirely within the St. Francois Mountains in St. Francois and Madison counties, likely forming on the basal portion of the Lamotte Sandstone. The second area occurs entirely within the Inner Ozark Border Subsection mostly in Ste. Genevieve County where the finer sands of the upper facies of the Lamotte Sandstone are found. The Lamotte Sandstone appears to be absent in the western portion of Madison County and outcrops do not completely encircle the St. Francois Mountains on its west side where some locations have igneous rocks directly overlain by the Bonneterre Formation.

TOPOGRAPHIC RELATIONSHIP TO DISTRIBUTION PATTERNS

Lamotte Sandstone is the basal sedimentary Cambrian layer which, where present, sits on Precambrian-age igneous rock. It immediately underlies the Bonneterre Formation. Both outcrop near the St. Francois Mountains. The Lamotte Sandstone is exposed along the north and eastern flanks of the St. Francois Mountains across an undulating level plain periodically incised by streams that cut downward through the Lamotte Sandstone layer. The down cutting often creates sandstone cliffs and small canyons. Glades are often positioned at the crests of steeper cliff ledges, or on midslopes of more gently sloping hills in valleys. Most of the glades are exposed by the headwater cutting of Doe Run Creek, and the Wills Branch and Rock Creek drainages of the Little St. Francis River centered on the S Bar F Scout Ranch (Fig. 6-4). Glade positions range from 800 to 900 feet in elevation. The second area occurs east of Farmington within the Inner Ozark Border where glades occur along upland gentle slopes of headwater drainages, eventually following the same elevations into more deeply cut hills and sandstone knobs. These glades occur in the upper drainages of Pickle, Sand, Bear and Bleu creeks, and River aux Vases near Hawn State Park (Ste. Genevieve County). Elevations range from 800 to 900 feet.

Sandstone glades occur on all aspects (Fig. 6-5) at equal elevations where erosion cuts through the most erosion-resistant portion of the formation. Their slopes range from 5-10% on gentle slopes, to as high as 25% along deeply incised streams. Ninety-nine sandstone glades are centered 2 miles east of S Bar F Ranch headquarters in St. Francois and Madison counties. Twenty of these glades occur on essentially level terrain.

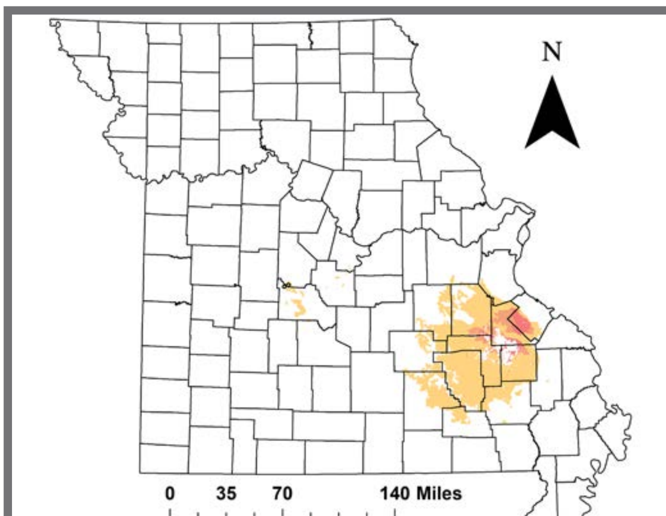

Figure 6-1. *Outcrop pattern of Cambrian-age rock units (expanded Fig. 6-2).*

LITHOLOGY, SHAPE AND SIZE

Within and surrounding the eastern flanks of the St. Francois Mountains, the lowest layer of the Lamotte consists of eroded, coarse material originating from the adjacent volcanic terrane. Above this base the Lamotte is predominantly quartzose sandstone although some silty shales and sandy dolomite may be locally present in the upper sections of the formation. In deep depressions between igneous hills and knobs, the Lamotte Sandstone can reach a maximum thickness of 500 feet, thinning rapidly where it laps on adjacent igneous hills and knobs (Thompson, 1995).

Lamotte glades are roughly oblong ellipsoid to circular-shaped. Most are several hundred feet long and 200 feet wide with the largest 50 glades averaging 2.4 acres. The longest and largest is one-half mile by 300 feet totaling 11 acres (Fig. 6-4). Density is dense to widespread for the two primary clusters. Glade exposures are easy to detect on aerial images owing to their stark light gray to white appearance where bedrock is covered by lichens and mosses. Unlike dolomite and limestone bedrock, the weathering of Lamotte Sandstone bedrock often results in irregular, variably raised areas of rounded bedrock interrupted by deeply weathered fractures and crevices, that are sometimes occupied by stunted small oak trees and shrubs. A 50-foot mass of castellated, turret-like, byzantine rock mounds (Fig. 6-6) is present at S Bar F Scout Ranch in St. Francois County. These rounded masses of sandstone owe their appearance to the process of erosion carving through widely spaced fractures through the sandstone. Large boulders are sometimes scattered over bedrock. Large-grained, weathered sand or gravel particles collect in crevices, joint fractures, base of ledges and edges of the glade.

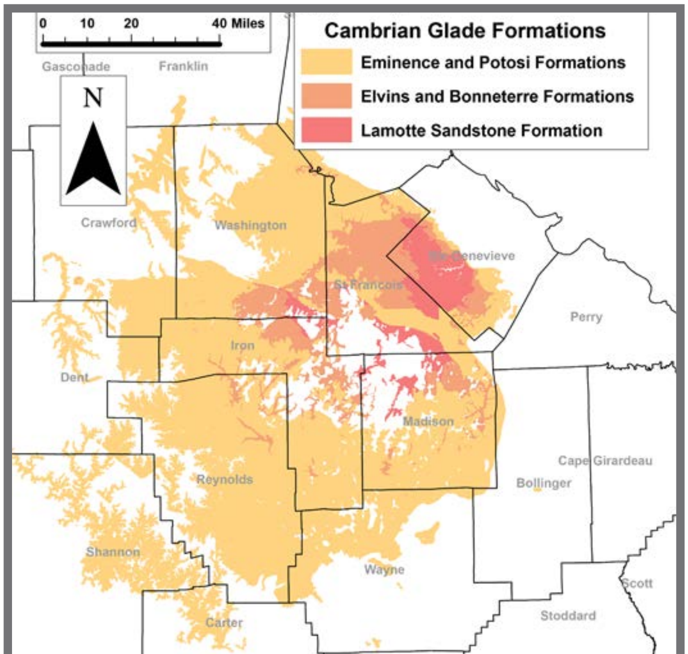

Figure 6-2. *Locations of the three Cambrian-age glade-producing formations: Lamotte Sandstone (Middle Cambrian Age); Elvins Group-Bonneterre Formation (Middle/Upper Cambrian Age), and Eminence and Potosi formation (Upper Cambrian Age).*

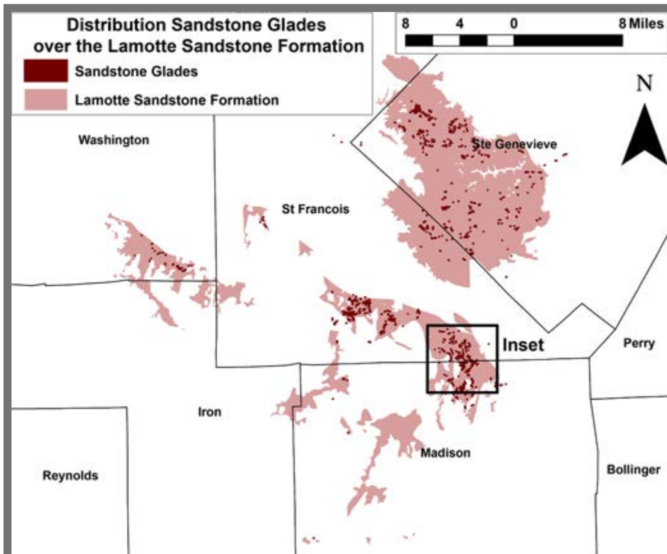

Figure 6-3. *Distribution of Lamotte Sandstone glades centered around Farmington in St. Francois County. Note: inset expanded in Figure 6-4.*

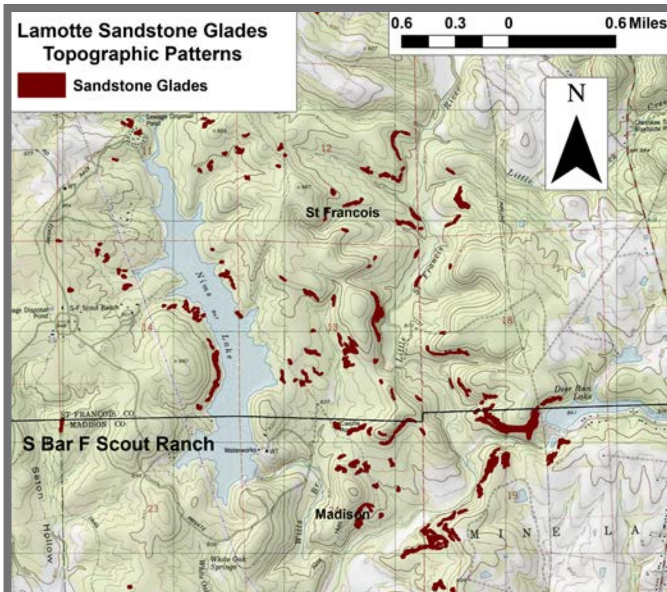

Figure 6-4. *Lamotte Sandstone glades shown in inset in Figure 6-3.*

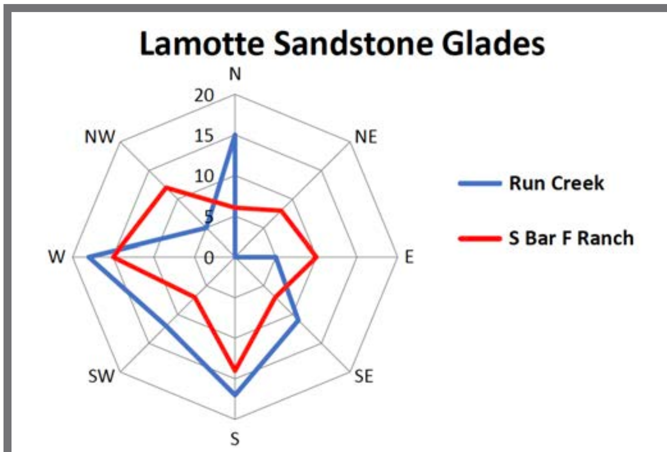

Figure 6-5. *Aspect for 80 sandstone glades situated in the upper Run Creek watershed 3.5 miles southeast of Doe Run in St. Francois County.*

PUBLIC LAND LOCATIONS AND FUTURE PROTECTION OPPORTUNITIES

Hickory Creek Canyons Natural Area (Ste. Genevieve County) contains 34 glades totaling 17 acres. Hawn State Park protects 19 relatively small glades totaling 10 acres, which includes the Lamotte Sandstone Barrens Natural Area (Fig. 6-7). Eleven miles southeast of Farmington in St. Francois County, the approximate 9-square-mile S Bar F Scout Ranch contains 123 glades totaling 75 acres. This showcase includes nearly 11 acres, the largest mapped glade. With more than 22 EORs for sandstone glades, cliffs, woodlands and associated rare species, this premiere Lamotte landscape should be a high-priority cooperative conservation effort with the Boy Scouts of America.

Figure 6-6. *Castellated, turret-like, byzantine rock mounds at S Bar F Scout Ranch in St. Francois County.*

Figure 6-7. *Lamotte Sandstone Barrens Natural Area, Hawn State Park in Ste. Genevieve County.*

MIDDLE/UPPER CAMBRIAN-AGE GLADE-PRODUCING FORMATIONS

ELVINS AND BONNETERRE DOLOMITE GLADES

Number of glades	1,531
Minimum size	0.04 acre
Maximum size	29 acres
Total acreage (sum)	1,800 acres
Mean size	1.2 acres
Maximum perimeter	2.6 miles
Total perimeter	364 miles
Mean perimeter	0.2 mile
Pattern density	Widespread to scattered
Classification – Terrestrial Natural Communities of Missouri (Nelson, 2010)	Dolomite glade natural community
Classification – International Ecological Classification Standard (Nature Serve, 2009)	Ozark Dolomite Glade

Table 6-2. *Statistical summary of Elvins and Bonneterre dolomite glades.*

The Elvins Group (hereafter referred to the Elvins and Bonneterre) includes the Derby-Doe Run and Davis formations and overlie the Bonneterre Formation. The authors do not attempt to identify the specific glade-producing strata as geologic data and EORs vary between the Bonneterre, Davis, and Derby Doe Run formations. The Elvins Group is overlain by the Potosi Dolomite while the Bonneterre is underlain by the previously described Lamotte Sandstone.

MISSOURI DISTRIBUTION

The Elvins and Bonneterre formations radiate outward in an irregular broken arc extending northwest, north, then northeast to east roughly 15 miles from the edge of the igneous knobs transitioning into undulating plains and hills. The eastern portion of this narrow arc is bisected by the most extensive portion of the Lamotte known as the Lamotte basin. West of the St. Francois Mountains, this zone becomes highly fragmented and isolated, gradually fading where eroded along the southern border of the St. Francois Mountains. Five clusters of concentrated Elvins and Bonneterre glades are scattered within and to the north of the St. Francois Mountains with the largest cluster centered just south-west of the town of Bonne Terre. The first cluster is located along eastern side of the northeast-southwest trending Big River Fault along the western boundary of St. Francois County. While all glades are in the Elvins and Bonneterre group, those present on the down-thrown northwest side of the fault are located higher in the stratigraphic section. Another localized, disjunct cluster of Elvins and Bonneterre glades is centered in Washington State Park (Washington County) situated on up-thrown blocks where complex faulting exposed the formation.

Figure 6-8. *Elvins and Bonneterre dolomite glade 1 mile southwest of Bonne Terre in St. Francois County.*

TOPOGRAPHIC RELATIONSHIP TO DISTRIBUTION PATTERNS

Elvins and Bonneterre glades occur on gently rolling hills and valley floors as determined by the elevation of the primary glade-producing strata. Most dolomite glades are found between elevations ranging from 790 to 1,200 feet. The cluster of 250 plus glades immediately west of the town of Bonne Terre demonstrate the change in topographic position as determined by their spatial relationship to the Big River Fault complex. To the east, glade groupings occur toward the tops of broad hills at 1,000 feet in elevation while to the west, groupings descend to the base of hills and into valleys below 900 feet. A similar pattern is repeated for some 250 glades occupying the broad Arcadia valley west of Buford Mountain (Iron County). The Belleview valley basin is the result of a large northwest to southeast-trending graben structure bound to the east by the Ironton Fault and to the west by the Belleview fault. These glades occur along the lower slopes of dissected hills between 1,000 and 1,200 feet in elevation. The extent of glades ends abruptly along the edge of the high ridge to the west and north. To the east of the St. Francois Mountains, portions of the Elvins and Bonneterre formations occur at lower elevations of the western uplifted portion of the Higdon and Mine Lamotte fault zones within the Inner Ozark Border Subsection.

LITHOLOGY, SHAPE AND SIZE

The glade-producing strata on any single hillslope can drop 80 feet in relief. The 50 largest glades range from 6 to 29 acres with a mean of 10 acres. The longest glade perimeter is 2.6 miles. More than 250 were mapped within a 12-square-mile area resulting in several dense clusters north and west of Bonne Terre. Density is widespread to the east of Farmington.

Generally, glade shape outlines are irregular and patchy with ragged, somewhat amoeboid edges. Where the strata are exposed on hill midslopes, glades occur in closely spaced chains often regardless of aspect and at the same contour elevation. These gentle hillslope glades slope from 5-20%. However, where the strata are exposed on broad flat high points or hilltops, glades are generally flat to gently-sloping. These same "flatrock" exposures also occupy the lowest flatlands of the Arcadia Valley basin, especially prominent at the base of Buford Mountain immediately northeast of the intersection of state Routes 96 and U. In this area, 31 were mapped (one 29 acres) totaling 112 acres, all occupying a 1-square-mile area and with an elevation difference of less than 20 feet. Flatrock glades range from 0% to 10 % slopes. Figure 6-11 indicates nearly 25% of all glades have extensive flatrock pavement.

Many glades are characterized by areas of flatrock pavement (Fig. 6-13), often forming elevated rock-wall ledges and isolated blocks. Aerial views reveal extensive exposures of flatrock with open rectangular or checkerboard fractures often tens of feet square. These flatrock fracture patterns help identify and locate glades on aerial images. Some of these exposures may be due to historical surface mining or stripping of barite. Large flat boulders or flagstone are scattered across a matrix of shallow dolomite gravel and small stones.

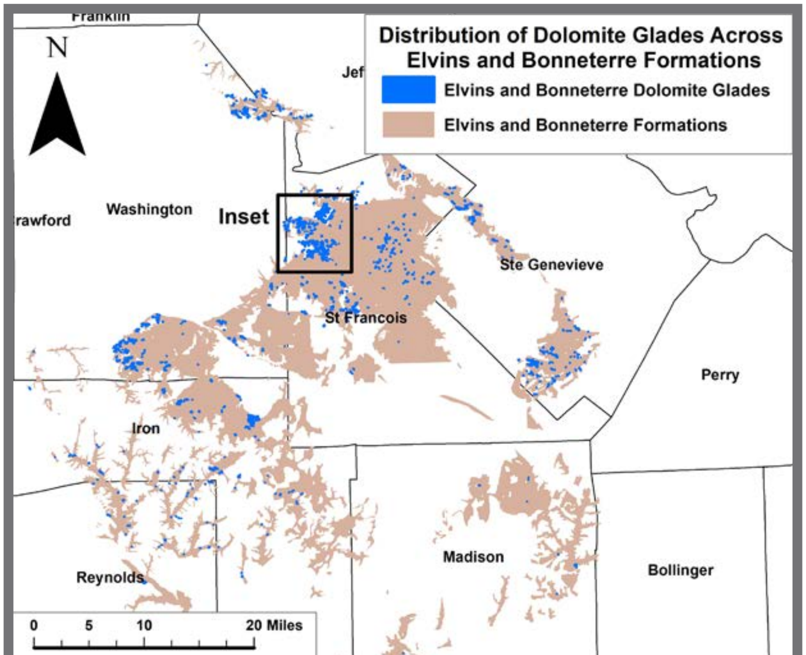

Figure 6-9. *Distribution of Elvins and Bonneterre glades in east-central Missouri. Inset shown is expanded in Figure 6-10.*

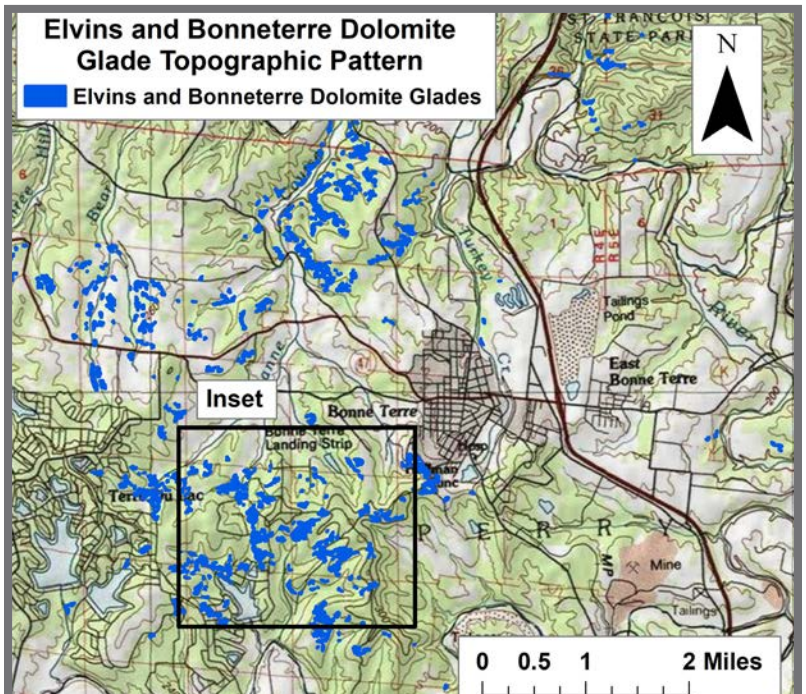

Figure 6-10. *Expanded view of inset in Figure 6-9 depicting distribution of Elvins and Bonneterre dolomite glades in relationship to topography. Figure 6-11 is an expanded view of the inset in the lower center.*

PUBLIC LAND LOCATIONS AND FUTURE PROTECTION OPPORTUNITIES

Washington State Park (Washington County) protects 25 dolomite glades of the Derby-Doe Run Formation within the Elvins Group. These glades encompass 106 acres including one 28-acre glade. Substantial populations of prairie iris (*Nemastylis geminiflora*) occur on portions of the 37 glades in St. Joe State Park (St Francois County). Buford Mountain in Iron County has 34 total acres on six cedar-dominated glades.

The largest complex (and perhaps the highest quality) of 450 glades more than 400 acres is concentrated within a 15-square-mile area immediately west of the town of Bonne Terre in St. Francois County. Conservation entities should inventory these glades and consider protection strategies.

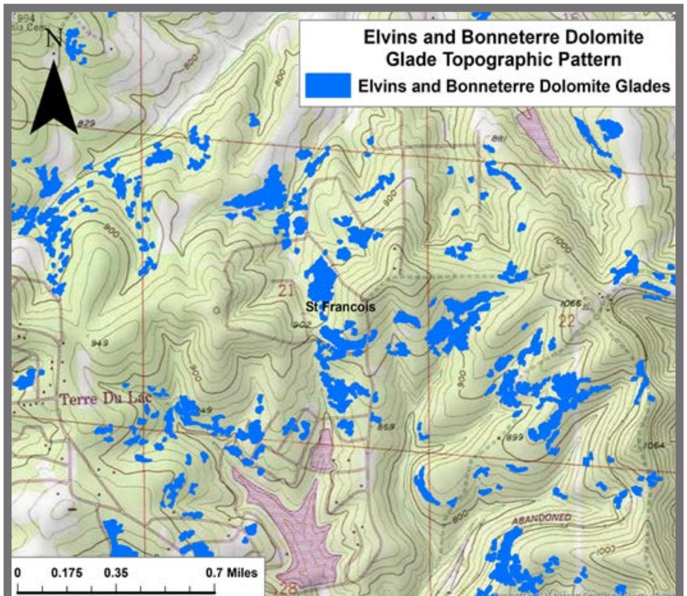

Figure 6-11. *Expansion of inset in Figure 6-10.*

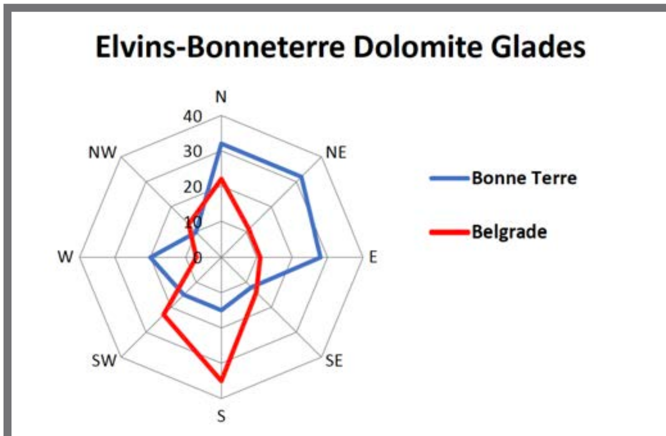

Figure 6-12. *Two different aspect orientations for 150 glades (examined within 12-square-mile blocks) centered 2 miles southwest of the town of Bonne Terre in St. Francois County, contrasting a second area near the town of Belgrade in Washington and Iron counties. The Bonneterre complex is oriented primarily north and east while the Belgrade glades form an axis of north and south-facing glades.*

Figure 6-13. *One of many flatrock dolomite glades characteristic of the Elvins and Bonneterre glades. West of Park City in St. Francois County.*

UPPER CAMBRIAN-AGE GLADE-PRODUCING FORMATIONS

EMINENCE AND POTOSI DOLOMITE GLADES

Number of glades	2,169
Minimum size	0.02 acre
Maximum size	48 acres
Total acreage (sum)	2,187 acres
Mean size	01.0 acre
Maximum perimeter	3.1 miles
Total perimeter	431 miles
Mean perimeter	0.2 mile
Pattern density	Scattered to isolated
Classification – Terrestrial Natural Communities of Missouri (Nelson, 2010)	Dolomite glade natural community
Classification – International Ecological Classification Standard (Nature Serve, 2009)	Ozark Dolomite Glade

Table 6-3. *Statistical summary of Eminence and Potosi dolomite glades.*

MISSOURI DISTRIBUTION

The Cambrian-age Eminence and Potosi dolomites are the next youngest in the geologic sequence, and youngest of the Cambrian-age units. They extend 40 miles outward from the center of the St. Francois Mountains where they are overlain by the easternmost extent of the Gasconade Formation. However, 15 miles further from this margin the Meramec, Big and Current rivers carve deep enough through younger Ordovician-age units to expose the Eminence Dolomite along high cliffs and on steep ends of narrow ridge points in deep river breaks and hills. Some 90 miles northwest, the Niangua River exposes the Eminence forming a small disjunct cluster of glades in Camden County near Ha Ha Tonka State Park, and an isolated occurrence associated with the Decaturville Impact Structure, a meteorite crater in Camden and Laclede counties.

Glades are generally scattered to widespread across this 90-mile-wide circular geologic region. Two dense glade clusters occur within this region. One cluster occurs along the Current River. Two localized clusters occur within the Big River watershed. The first is 5 miles north of Washington State Park (Washington County), and may be on the Potosi Dolomite. Another cluster is bounded on both sides by Mineral Fork Creek several miles west of Washington State Park.

TOPOGRAPHIC RELATIONSHIP TO DISTRIBUTION PATTERNS

The Eminence and Potosi dolomites produce massive bedrock as much as 350 feet thick. Eminence Dolomite glades are characteristically associated with cliffs and bluffs of the Current, Jack's Fork, and Eleven Point rivers in south-central Missouri, and with portions of the Meramec and Big rivers in east-central Missouri where these glades occur in widely spaced chains along the same elevation. Glades in south-central Missouri also generally occupy steep side slopes and end points near the crest of ridges and clifftops in deeply dissected hills and breaks associated with river drainages. Elevation averages 700 to 1,000 feet. To the east where the Eminence Dolomite dips abruptly along the Inner Ozark Border, scattered Eminence glade groupings occur on slopes of broadly dissected hills between 600 to 800 feet in elevation. Many glades occur in saddles of narrow exposed ridges.

Figure 6-14. *Eminence and Potosi glade in St. Francois State Park, St. Francois County.*

LITHOLOGY, SHAPE AND SIZE

Shapes generally range from circular to oblong-elongated, but rarely resemble the crescent-shaped glades characteristic of Jefferson City and Gasconade dolomite glades. Perimeters are generally wavy, but rarely amoeboid. The glade-producing strata on any single hillslope vary from 20 feet to 80 feet in relief. Slope varies from 0% to 10% where exposed on level ridges and saddles to 10% to 45% on steep slopes of hills and breaks. The 50 largest glades totaling 490 acres range from five to 48 acres with a mean of nine acres. The longest perimeter is 3.1 miles for the largest 48-acre glade (Fig. 6-18), situated in the area of the Decaturville Impact Structure.

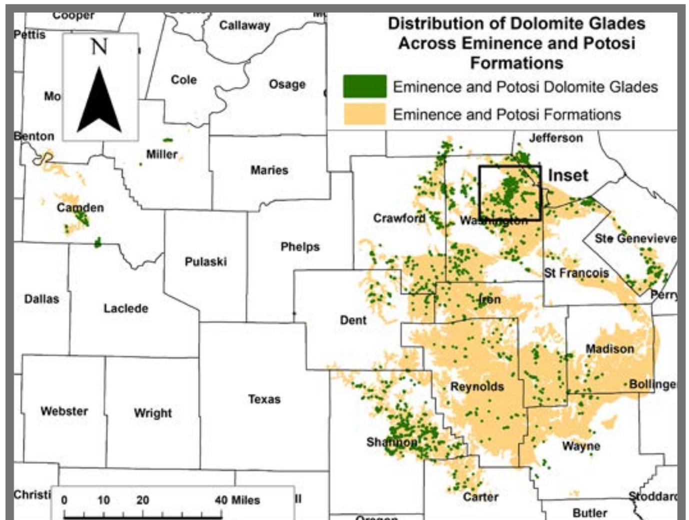

Figure 6-15. *Distribution of dolomite glades across Eminence and Potosi geologic units. An expanded view of the inset is shown in Figure 6-16.*

Eminence and Potosi dolomite glades differ from other dolomite glades in their craggy, irregular, often jagged rock outcrops, rock pinnacles and stones ranging from 1 foot to 4 feet high. Weathered solution pits and cavities often cover the surface of these exposed rocks giving them a Swiss cheese appearance. Unlike other sedimentary dolomites, Eminence outcrops do not readily form stratified, even layers of alternating ledges and level pavement along vertical planes. Figure 6-17 clearly indicates these glades have a strong affinity to south through west exposures. North, northeast and east-facing glades are rare.

PUBLIC LAND LOCATIONS AND FUTURE PROTECTION OPPORTUNITIES

Meramec State Park (Franklin, Crawford and Washington counties) protects 48 Eminence and Potosi dolomite glades totaling 48 acres. Meramec Mosaic Natural Area contains the largest of these glades. Ha Ha Tonka State Park (Camden County) protects the best examples of this glade type, which occurs in a disjunct outcrop of the Eminence some 75 miles northwest of the primary distribution. More than 136 glades totaling 206 acres occur in over 215,000 combined acres of MDC lands in Shannon County. Pea Ridge Conservation Area in Washington County also protects dolomite glades. MTNF, particularly the Salem-Fredericktown ranger districts, also protects substantial numbers of this glade type.

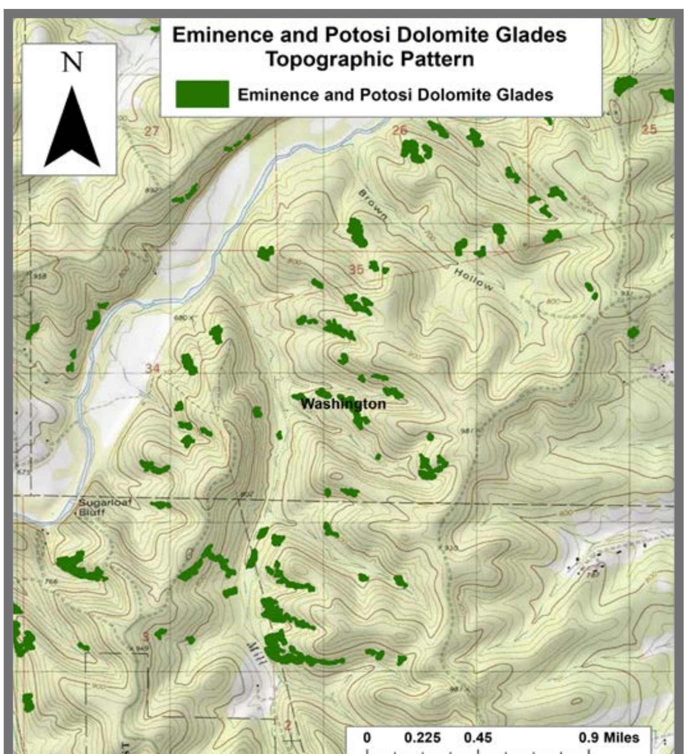

Figure 6-16. *Expanded view of the inset in Figure 6-15, depicting the topographic pattern of Eminence and Potosi dolomite glades along Mineral Fork Creek 4 miles northwest of Old Mines, Washington County.*

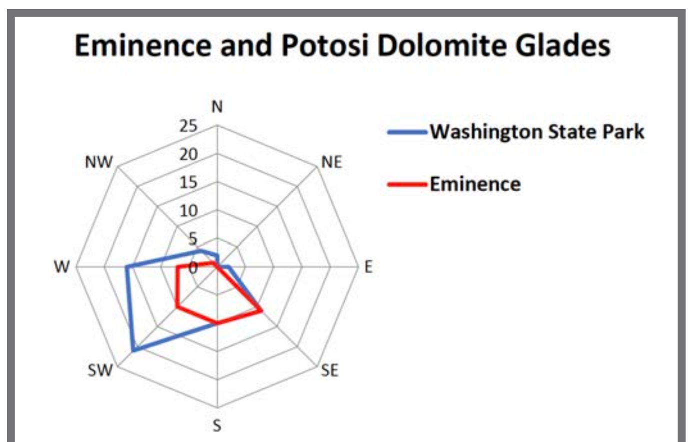

Figure 6-17. *Aspect for 72 Eminence and Potosi dolomite glades five miles southwest of Washington State Park in Washington County (six glades on level terrain), and 45 glades centered three miles north of Eminence in Shannon County (six glades on level terrain).*

Figure 6-18. *Missouri's largest Eminence and Potosi dolomite glade (48 acres) occurs within the Decaturville Impact Structure in Camden County. A meteorite struck earth some 300 million years ago overturning the geologic layers beneath (Spencer and Oboh-Ikuenobe, 2019). Subsequent geologic processes exposed the strata. Today, five glade types totaling 265 acres occur in concentric rings in a 5-mile-wide circle.*

Chapter 7.
Ordovician-Age Glade-Producing Formations

From oldest to youngest, the lower Ordovician-age, Gasconade, Roubidoux, and Jefferson City formations form oblong-elliptic circles some 190 miles across (Fig. 7-1). The elliptic circle is longest where it extends some 160 miles west of the St. Francois Mountains. The Jefferson City Dolomite forms the outermost elliptical band and is the most extensively exposed surface formation of the Central Plateau, White River Hills, Osage River Hills and Inner Ozark Border subsections. The Roubidoux Formation makes up the next inner elliptical circle, sandwiched between the older Gasconade Dolomite and the younger Jefferson City Dolomite. The Roubidoux is prominent in many areas as it is the uppermost unit underlying large portions of the Salem Plateau. When overlain by the Jefferson City, streams and rivers cut deeply through the overlying formation exposing the Roubidoux along dissected hills, sideslopes and valleys. The Roubidoux overlies the Gasconade Dolomite and is also the most extensive surface formation in portions of the Central Plateau and most of the Black River Ozark Border Subsection in southeastern Missouri.

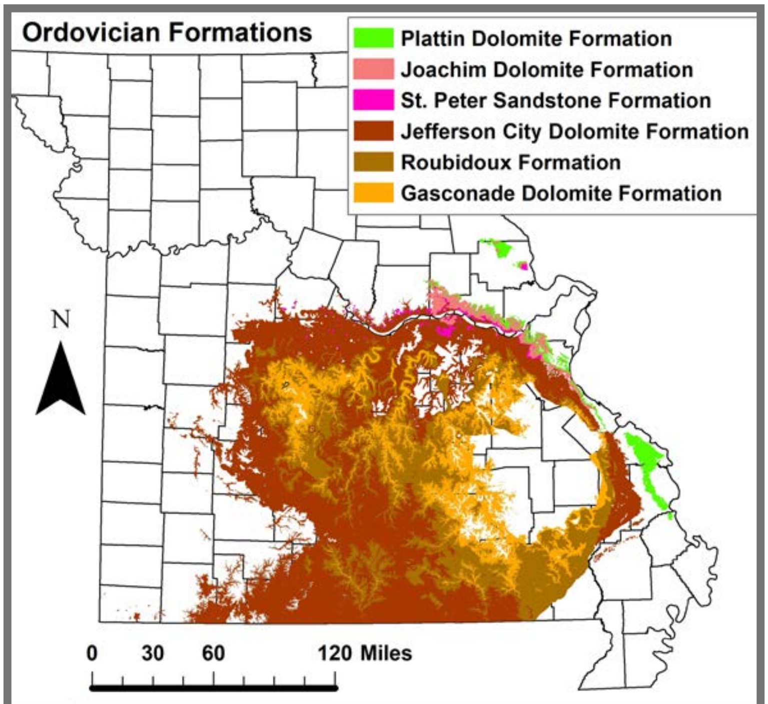

Figure 7-1. *Outcrop pattern of Ordovician-age rock units.*

LOWER ORDOVICIAN-IBEXIAN-AGE GLADE-PRODUCING FORMATIONS

GASCONADE DOLOMITE GLADES

Number of glades	12,033
Minimum size	0.02 acre
Maximum size	38 acres
Total acreage (sum)	11,025 acres
Mean size	0.69 acre
Maximum perimeter	4.0 miles
Total perimeter	2,402 miles
Mean perimeter	0.2 mile
Pattern density	Widespread to scattered
Classification – Terrestrial Natural Communities of Missouri (Nelson, 2010)	Dolomite glade natural community
Classification – International Ecological Classification Standard (Nature Serve, 2009)	Ozark Dolomite Glade

Table 7-1. *Statistical summary of Gasconade Dolomite glades.*

Figure 7-2. *Gasconade glade in the Niangua River Basin. Ha Ha Tonka Oak Woodland Natural Area, Ha Ha Tonka State Park, Camden County.*

MISSOURI DISTRIBUTION

The Gasconade Dolomite overlies the Eminence and Potosi forming an irregular outer ring around the fringes of the St. Francois Mountains. The formation dips gradually westward for 20 to 30 miles where it contacts the overlying Roubidoux in Carter, Shannon, Dent, Crawford and Franklin counties. As the Gasconade's layers dip into stream and river valleys of deeply dissected hills, the outer west and north fringe becomes dendritic. Further west and north extending 80 miles, the Gasconade Dolomite dips deeper below the rising Springfield Plateau, essentially defined by the Central Plateau Subsection. Only the Osage, Gasconade and Meramec rivers carve deep enough into the plateau to again exhume and expose dendritic patterns of the Gasconade. Outcrop patterns on the east and northeast side of the St. Francois Mountains occupy a relatively thin band as the units quickly descend into the Illinois Basin. This bedrock is prominent in the narrow Inner Ozark Border Subsection.

TOPOGRAPHIC RELATIONSHIP TO DISTRIBUTION PATTERNS

Examination of the distribution map reveals a direct relationship between the primary clusters of glades and major river systems. The highest concentration of glades occurs throughout the Niangua River (Fig. 7-4) and lower portions of the Osage River basins. Glades are dense with greater than 150 within 12-square-mile blocks throughout the Niangua River drainage stretching from Ha Ha Tonka to Bennett Spring state parks. Elevation ranges from 700 to 950 feet. To the east, the Roubidoux overlies the Gasconade across the higher plains and plateaus of the Central Plateau Ecological Subsection (Nigh and Schroeder, 2002). Approximately 20 miles to the east, the deeply entrenched Gasconade River has cut through and removed a large portion of the overlying Roubidoux, again exposing widespread glade densities of the Gasconade Dolomite. Finally, the Gasconade is exposed in a 20-30-mile-wide band surrounding the St. Francois Mountains with widespread exposures of glades associated with the Current, Eleven Point, Meramec, Big, Bryant and North Fork rivers (Fig. 7-8). An exception to the otherwise typical occurrence of these glades in deeply dissected river systems is the presence of glades across portions of the gently rolling plains on the Central Plateau, especially near Houston in Texas County (Fig. 7-10).

The radial aspect chart (Fig. 7-7) indicates the dominant south-facing aspect of 420 selected glades in three different areas. In the Niangua River basin, 189 glades occur in a 12-square-mile area in Ha Ha Tonka State Park in Camden County (Fig. 7-5). One hundred miles to the east, the aspect polygon of 156 glades centered around Pea Ridge Conservation Area in Washington County nearly match the polygon of Ha Ha Tonka State Park. In contrast, nearly 100 miles to the southeast in Shannon County, only 59 occur within a 12-square-mile area centered near Echo Bluff State Park also facing southward on steep bluffs along the Current River (Figs. 7-8 and 7-9). These glades occur at elevations between 700 to 1,000 feet. Many continuous and braided strands of glades on top of bluffs clearly define the presence of meandering entrenched high cliffs, especially prominent between Jerome in Phelps County and Slabtown in Texas County. A localized cluster occurs in the Saline Creek drainage at elevations between 500 and 700 feet where a narrow band of the Gasconade Dolomite occurs along the narrow arc of the Ozark Border in Ste. Genevieve and Perry counties.

Unlike the Jefferson City glades, few Gasconade glades are oriented north of a west-east line (Fig. 7-9). Only 4% occur on nearly neutral aspects. Most of the south-oriented glades occur along elongated ridges, steep bluffs along rivers, clifftops, and nose slopes at the endpoints of steep abrupt ridges. Because of the uniform nature and thickness of the Gasconade Dolomite, many glades are elongated along south-facing steep ridges with many approaching one half to one mile in length and nearing 1,000 feet wide. The Gasconade Dolomite is the characteristic bluff-forming geologic unit along the Gasconade River drainage where chains of continuous prominent-elongated glades line the crest of cliffs situated along the cut side of many entrenched concave meanders of the river. A few balds occur, especially in the Osage River drainage. These bluff glades are rugged and steep with 20 to 45-degree slopes.

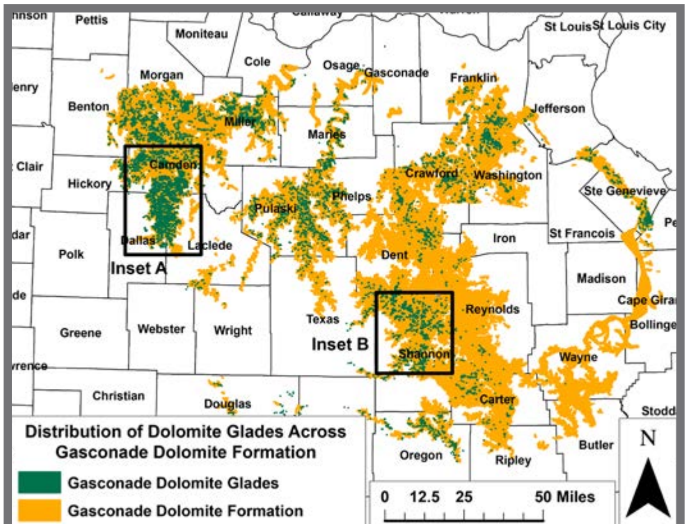

Figure 7-3. *Distribution of Gasconade Dolomite glades in the central Ozarks of Missouri. Inset A is expanded in Figure 7-4. Inset B is expanded in Figure 7-8.*

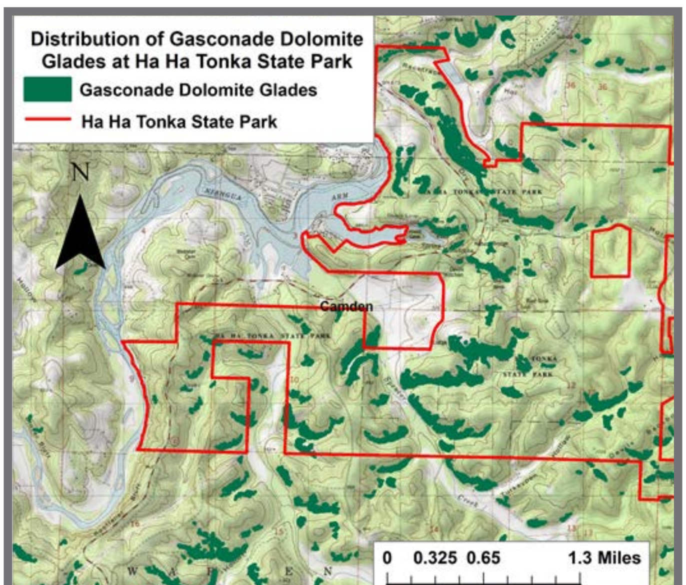

Figure 7-5. *View of inset in Figure 7-4 of glade topographic patterns at Ha Ha Tonka State Park, Camden County.*

LITHOLOGY, SHAPE AND SIZE

Gasconade Dolomite is predominately a light brown to brownish gray, medium to coarse crystalline dolomite to cherty dolomite. Throughout the Ozarks, the formation averages nearly 300 feet in thickness. The well-defined bedding thickness results in the consistent presence of large Gasconade Dolomite glades. Approximately 30 feet from the base of the formation is a persistent quartzose sandstone member called the Gunter Sandstone. Above this sandstone the dolomite contains large amounts of

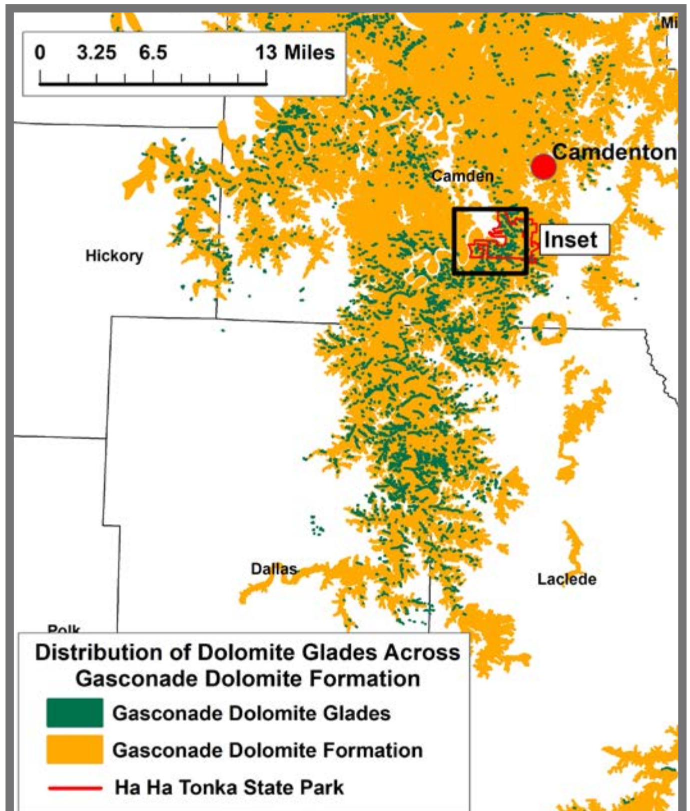

Figure 7-4. *Close-up of inset A in Figure 7-3 for Missouri's largest complex of Gasconade Dolomite glades, Niangua River Basin.*

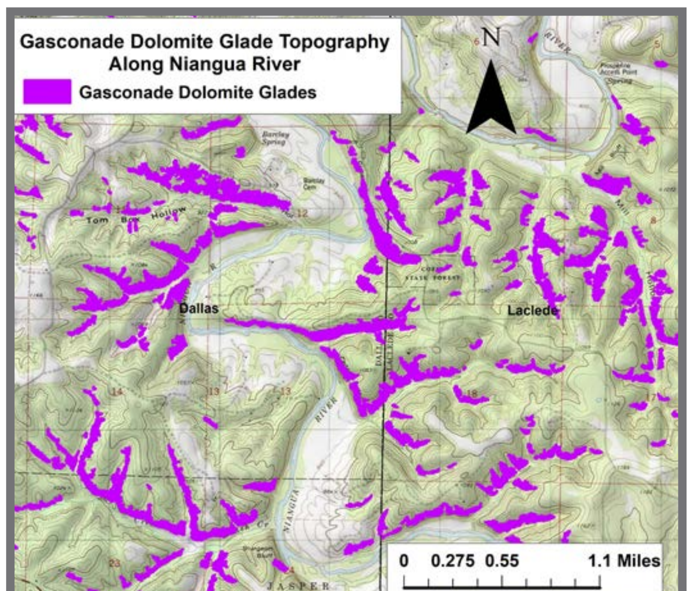

Figure 7-6. *Typical topographic pattern of Gasconade Dolomite glades primarily restricted to southward-facing steep hillslopes in the Niangua River basin, Dallas County.*

oolitic and smooth, white porcelaneous chert often said to have a "dead" appearance (Thompson, 1995). This cryptozoan chert often forms a uniform broken layer of large three to 4-foot-high cabbage-banded fossilized algal (stromatolite) boulders and broken ledges. Below the Gunter Sandstone Member, the gray and brown banded chert diminishes greatly.

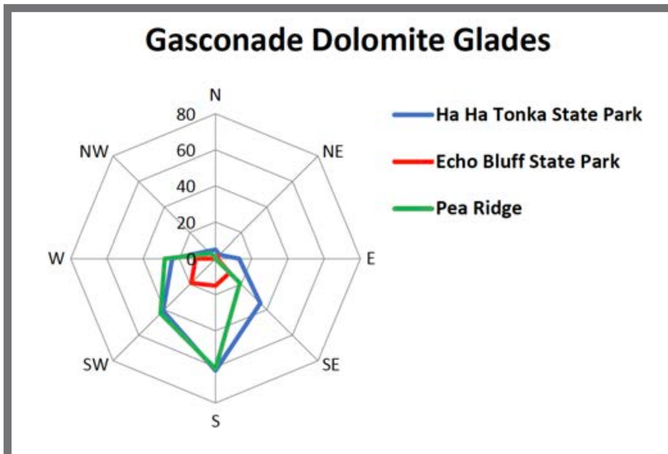

Figure 7-7. *Radial aspect chart of three Gasconade Dolomite glade complexes.*

Unlike the blocky bluffs and massive ledges found on Eminence Dolomite glades, Gasconade Dolomite glades appear uniformly worn over relatively steep slopes (15% to 35%) and can range in elevation thickness of 10 feet for small glades to 150 feet for large glades. These thickest of Gasconade Dolomite glades occur throughout the Niangua River basin as seen at Ha Ha Tonka State Park. Well-defined uniform bedding results in outcrops of steps and ledges following zoned contours. Stony small boulders and chert gravel are conspicuously strewn over the surface. A more persistent stepped rock ledge zone or uniform outcrop often is situated along the lower slope or base of large glades. Calcareous seeps (and to a lesser extent Ozark fens) are prevalent along and below this rather impervious bedding zone. Small seep rivulets surfacing through holes along this zone deposit white calcite and marl.

More than 12,000 Gasconade glades occur totaling almost 11,000 acres. Nearly 7,000 (more than 50%) occur in the Osage River drainage making this dissected river hill region the highest producer of Gasconade glades. Of the 50 largest glades, 60% occur in the Niangua River basin and include the largest at 38 acres.

PUBLIC LAND LOCATIONS AND FUTURE PROTECTION OPPORTUNITIES

Ha Ha Tonka State Park showcases high quality examples of dolomite glades. Other areas include Lead Mine, Mule Shoe, Peck Ranch, Indian Trail conservation areas and Meramec State Park.

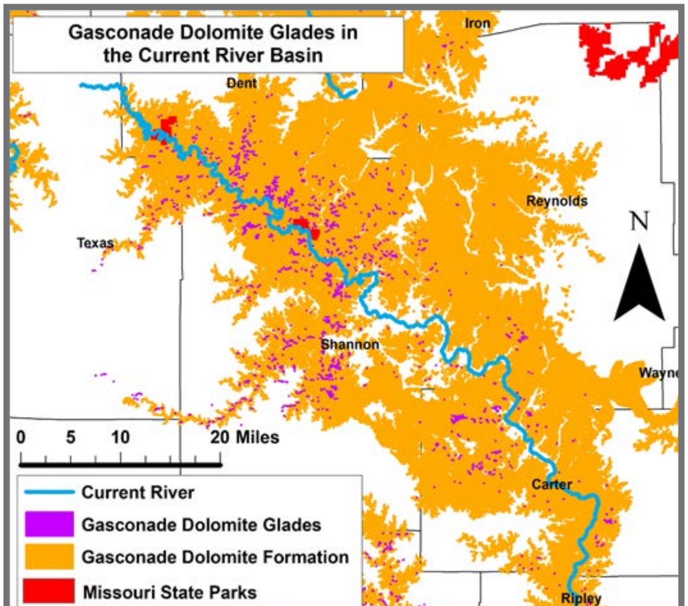

Figure 7-8. *Distribution of Gasconade Dolomite glades in the Current River basin in Shannon County.*

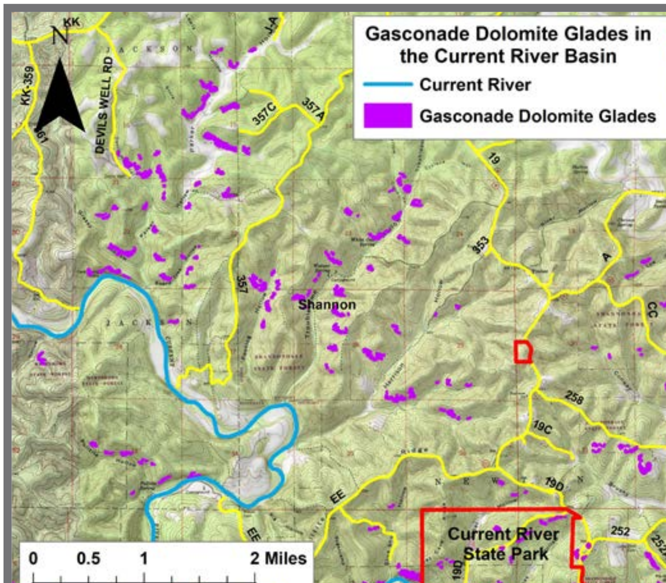

Figure 7-9. *Gasconade glade topographic patterns along the steep hills and breaks of the Current River in Shannon County. Note predominant southerly exposures.*

Figure 7-10. *Gasconade glade on relatively level terrain typical of the Central Plateau three miles south of Houston in Texas County.*

ROUBIDOUX FORMATION SANDSTONE GLADES

Number of glades	1,012
Minimum size	0.03 acre
Maximum size	4.0 acres
Total acreage (sum)	471 acres
Mean size	0.5 acre
Maximum perimeter	0.5 mile
Total perimeter	131 miles
Mean perimeter	0.1 mile
Pattern density	Isolated to scattered
Classification – Terrestrial Natural Communities of Missouri (Nelson, 2010)	Sandstone glade natural community
Classification – International Ecological Classification Standard (Nature Serve, 2009)	Ozark Sandstone Glade

Table 7-2. *Statistical summary of Roubidoux Sandstone glades.*

MISSOURI DISTRIBUTION

Despite the extent of the Roubidoux Formation on the Ozark land surface (Fig. 7-11), the actual occurrence of significant glade complexes is confined to two primary areas in central Missouri. The first and most extensive glade area stretches in a broad arc 90 miles long by 25 miles wide extending from southwestern Franklin County southwest to Texas County. The second disjunct area is situated in Miller County, one of nine counties with significant Roubidoux coverage and making up the Osage and Niangua River drainages. The Roubidoux is an extensive formation covering much of the land surface in southern-southeastern Missouri. However, the formation is primarily a cherty dolomite outside of the previous mentioned areas, thus few glades occur there. A few Roubidoux Dolomite glades may occur but are currently unknown.

The Roubidoux ranges from 90 to 235 feet in thickness and can be found across southern Missouri and the Ozarks. In the areas where sandstone glades are present, the lithology of the Roubidoux is primarily a fine- to medium-grained quartzose sandstone with minor interbedded sandy dolomites. Outside of the two glade-producing areas in central Missouri the predominant lithology of the Roubidoux is a cherty or sandy dolomite with as little as 10% sandstone present (Thompson, 1995). The more erosion-resistant sandstone units, forming massive, exposed ledges and fragmented blocks, gives the erroneous impression that sandstone is the primary rock type (Heller, 1954). However, sandstone is the primary glade-producing member of this formation.

TOPOGRAPHIC RELATIONSHIP TO DISTRIBUTION PATTERNS

Unlike other glade-producing rock formations, most Roubidioux Sandstone glades occur within small intermittent stream channels and headwater ravines. Sandwiched between the more soluble and erodible dolomite of the underlying Gasconade Dolomite and overlying Jefferson City Dolomite, the 15 to 30-foot-thick, uniform Roubidoux Sandstone layer typically forms midslope ledges and broken blocks along a steep "rim." Active downcutting of intermittent streams and runoff in draws and headwater valleys "scour" and expose Roubidoux Sandstone bedrock creating glade characteristics. In the steep dissected terrain of the Little Piney, Big Piney, Bourbeuse rivers, and tributaries of the upper Tavern Creek are found distinctive midslope "notched" valleys where stream runoff intercepts the upper Roubidoux Sandstone layer (Fig. 7-13). Many scoured glades contain cascade seasonal waterfall ledges, some greater than 20 vertical feet high. Of the total 79 glades examined, within 20 square miles centered along U.S. Highway 63 near Vida in Phelps County, 55 are assigned directional aspects. Of the 79 glades, nearly 70% are scour features.

Of the 140 glades within a 35-square-mile area centered near Mint Spring Conservation Area on the Gasconade-Crawford County line, 85 are assigned directional aspects (Fig. 7-14). The remaining 55 Mint Spring area glades occur on relatively flat terrain. Sixty percent of the 140 glades are scour features situated in gentle to moderately steep intermittent drainages of upper headwater ravines along the flanks of dissected plains. Renzer Creek polygon, highlighted in Figure 7-14, reflects only 31 of 75 total glades examined that have enough directional aspects.

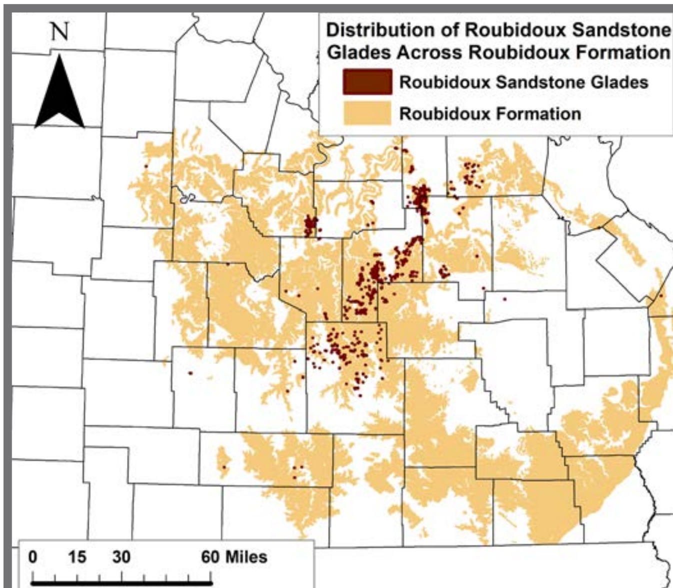

Figure 7-11. *Sandstone glade distribution across the Roubidoux. Note confined limits of glades in central portion of the formation range in Phelps, Shannon and Gasconade counties.*

LITHOLOGY, SHAPE AND SIZE

The Roubidoux Formation varies greatly across the state. In central Missouri, the Roubidoux is a prominent sandstone; however, across most of the state the formation consists of dolomite, cherty or sandy dolomite, or dolomitic sandstone. According to Thompson (1995) only about 10% of the formation is sandstone and across most of the state a cherty dolomite is the primary lithology. The glade-forming sandstone is typically a yellow to red, medium- to fine-grained quartzose sandstone when freshly broken (Fig. 7-15). When weathered, the unit is often a reddish-brown to reddish-gray and may be as much as 30 feet thick. Across the state, most of the formation is a light gray, finely crystalline cherty to sandy dolomite with scattered oolites.

Roubidoux Sandstone glades are differentiated from most other glade types by their relatively small size (less than 0.5 acres) and simple oblong-crescent shapes. A few are linear with irregular margins, the largest being just 4 acres. As Figure 7-13 demonstrates, 60% or more occur in association with or dissected by an intermittent stream or elevated headwater valley drainage. Crustose lichens dominate many glades owing to frequent runoff and sheet erosion. Lichen on exposed sandstone bedrock is readily visible in aerial imagery, aiding in recognition of sandstone glades as opposed to dolomite. For the most part, the density of glades is scattered to isolated with a few widespread occurrences. The scattered to isolated presence of these glades is due to the regular dendritic erosional patterns of stream and valley drainages predictably leaving one or two glades where the stream scours through the formation only once in the "head" above well-defined rim ledges or cliffs of

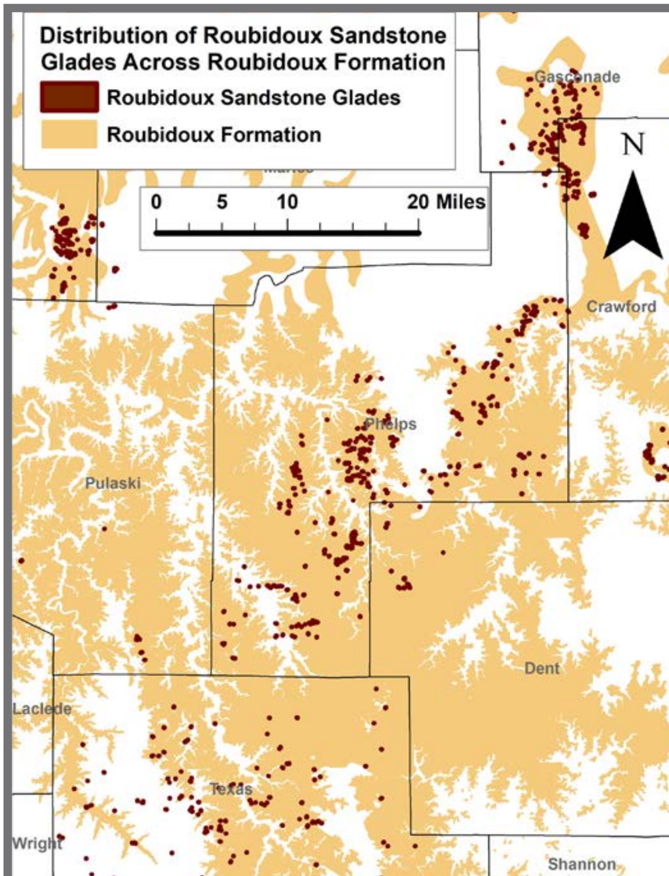

Figure 7-12. *Primary area of distribution for Roubidoux Sandstone glades centered around Rolla in Phelps County. Note the disjunct area of glades in southwest Miller County (northwest corner of the figure).*

each hillslope ravine. Mappers could predictably locate one or two glades in heads of deep valleys or draws extending along ridges.

Sandstone glade perimeters are among the shortest of any glade type, often less than 500 feet with the longest being one-half mile. Slopes are dependent on the relative position of the glade on hillsides or in low-gradient valleys adjacent to streams. Of all the glades examined and analyzed in Figure 7-14, 48 occupied relatively level terrain with slopes of 0% to 10%. Differential weathering produced by moderate gradient runoff through deep V-shaped valleys, as much as 30 vertical feet in a 200-foot run, often creates irregular potholes, plunge pools, ledges and falls as runoff dissects the sandstone units of the Roubidoux. These irregularities are accentuated by crossbedding of the sandstone. The 50 largest glades total only 93 acres with a mean of about 2 acres. The largest, at 4 acres, occurs in eastern Miller County in a tributary of Tavern Creek.

PUBLIC LAND LOCATIONS AND FUTURE PROTECTION OPPORTUNITIES

Approximately 110 sandstone glades totaling 50 acres occur on Houston-Rolla Ranger District, MTNF. Few significant glades occur on state-owned lands. Conservation organizations should inventory the two most significant complexes of this glade type, the first complex (Mint Spring area) where Gasconade, Crawford, and Phelps counties intersect, and the second complex (Kenzer Creek area) in extreme southeast Miller County.

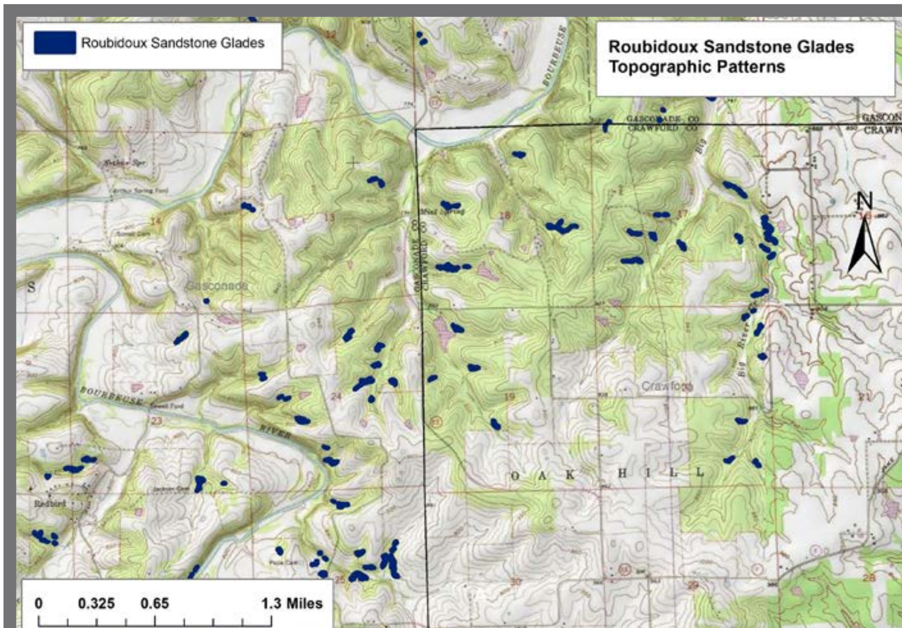

Figure 7-13. *Expanded map view of the isolated cluster of glades situated in the upper right corner in Figure 7-12 (Gasconade and Crawford counties) in relationship to topography. Most of the glades are scour features in headwater valleys between 840 to 940 feet in elevation.*

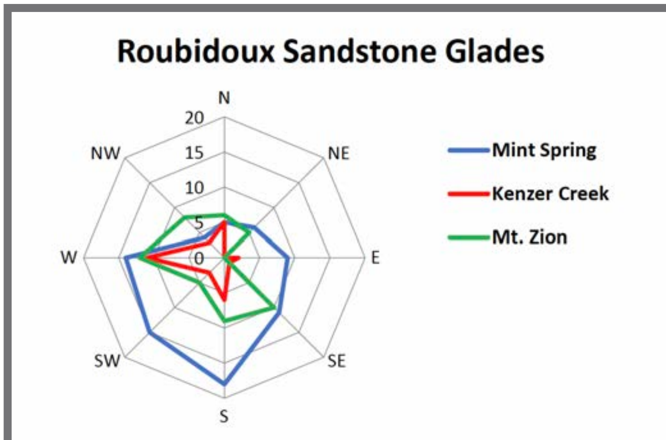

Figure 7-14. *Radial aspect chart for three 12-square-mile areas located in the primary Roubidoux Sandstone glade areas, including Mint Spring in Gasconade and Crawford counties, Kenzer Creek in Miller County, and Mt. Zion in Phelps County.*

Figure 7-15. *A recently broken sandstone (left) and a weathered Roubidoux Sandstone (right) surface in Franklin County. While the sandstone lithological units only make up about 10% of the Roubidoux Formation, they are the dominant glade producers of the formation. MoDNR photo by Pierce.*

Figure 7-16. *Freshly broken Roubidoux Sandstone surface, highlighting the quartz sand grains. MoDNR photo by Pierce.*

Figure 7-17. *Four-acre sandstone glade in the Kenzer Creek watershed, Miller County. Note scour channel in the center of the glade.*

Figure 7-18. *Roubidoux Sandstone glade in the Kenzer Creek watershed, Miller County, subject to upland headwater scouring during rain events.*

Figure 7-19. *Roubidoux Sandstone glade on MTNF, Texas County. The scour shown in the image terminates in a waterfall that cascades about 20 feet over a sandstone cliff.*

JEFFERSON CITY DOLOMITE GLADES

For decades, the Jefferson City Dolomite (Jefferson City) and the Cotter Dolomite units were mapped as a single mapping unit due to their lithological similarities and difficulty in distinguishing during fieldwork. However, recent micropaleontology investigations indicate that the Cotter Dolomite or age equivalent does not exist in the Missouri Ozarks or southern Missouri. The Cotter is only present in limited thin shale outcrops in the transition zone (Outer Ozark Border region of Fig. 4.4) between the Ozark Highlands and the Dissected Till Plains in Cooper and Pettis counties (Bridges, 2021). The lithological subunits such as Swan Creek Sandstone, Rockaway Beach Conglomerate and the finely crystalline "cotton rock" often associated with the Cotter Dolomite are in fact just subunits within the upper Jefferson City Dolomite.

As with the geologic nomenclature, for this report the name of Cotter Dolomite will be discontinued and any references to Cotter Glades or Jefferson City-Cotter glades in Missouri will be considered Jefferson City glades. The removal of Cotter from Missouri taxonomy and the finalization of this report coincide. While the name Cotter has been removed from the text of this report it does appear in some of the early produced figures.

It should also be noted that the Cotter Dolomite has been confirmed to be present in Arkansas and this name change only pertains to the Missouri portion of the Ozark Plateau as shown in Figure 4-1.

Figure 7-20. *Jefferson City glades characterize the White River Hills of southwest Missouri. Caney Picnic Shelter along the Glade Top Trail Scenic Drive, Taney County.*

Number of glades	50,416
Minimum size	0.01 acre
Maximum size	968 acres
Total acreage (sum)	132,778 acres
Mean size	2.6 acres
Maximum perimeter	56 miles
Total perimeter	17,159 miles
Mean perimeter	0.3 mile
Pattern density	Dense to widespread throughout range
Classification – Terrestrial Natural Communities of Missouri (Nelson, 2010)	Dolomite glade natural community
Classification – International Ecological Classification Standard (Nature Serve, 2009)	Ozark Dolomite Glade

Table 7-3. *Statistical summary of Jefferson City Dolomite glades.*

MISSOURI DISTRIBUTION

At more than 132,000 acres, the Jefferson City Dolomite is the largest glade-producing strata in Missouri. Since the Jefferson City can reach well more than 500 feet, the continuous thick bedding forms Missouri's largest glade region occurring in a broad circular arc outward from the St. Francois Mountains. This arc is narrowest to the northeast (15 miles wide) along the Inner Ozark Border Subsection (Fig. 4-4) and gradually widening to 70 miles in the White River Hills Subsection. Its southwestern-most terminus is nearly 180 miles from the center of the St. Francois Mountains where the glades are overlain by younger units of the Eureka Springs Escarpment that forms the southeastern portion of the Springfield Plain. These glades occur in nearly every portion of the Ozark Highlands but are nearly absent from the St. Francois Knobs and Basins, Meramec River Hills, Current River Hills, and Black River Ozark Border subsections.

Within this broad band circling the Ozark dome are several significant "trends" or clusters of tightly packed glades covering hundreds of square miles. Among these, two regions of glades stand out. The first region is the White River Hills Subsection where dolomite glades (Fig. 7-21, inset A) are a distinctive, characteristic, and scenically dramatic part of the landscape. No other region of the eastern U.S. comes close to the density of glades in the White River Hills. The Protem NE 7.5' quadrangle contains the highest density (Fig. 7-23) of these glades in all North America with 10,288 acres (28%) within the 38,528-acre map. Missouri's most dramatic glade landscape inspired early explorers, travelers, writers, botanists, biologists, and settlers to write about them. Numerous biological studies attest to their ecological importance and global significance. A second and formerly lesser-known region is the broad arc of highly concentrated, large Jefferson City glades trending more than 80 miles from Perryville to near Union, centered in Jefferson County (Fig. 7-24).

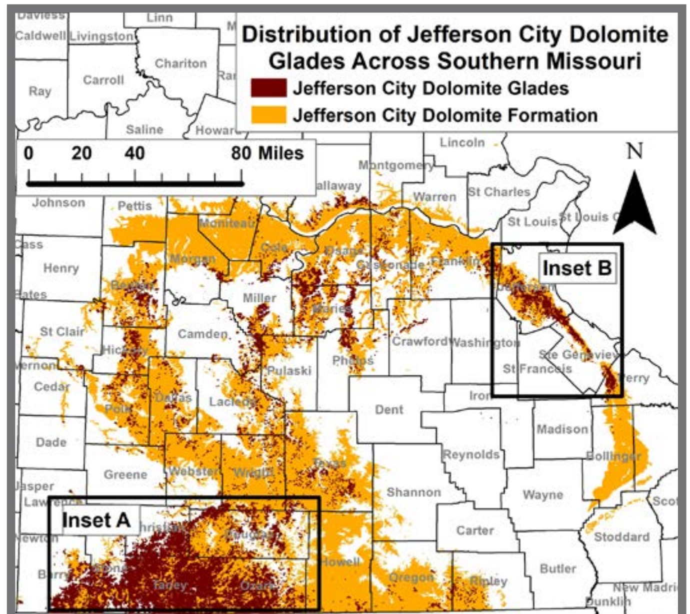

Figure 7-21. *Distribution of Jefferson City glades across Missouri. Note insets A and B.*

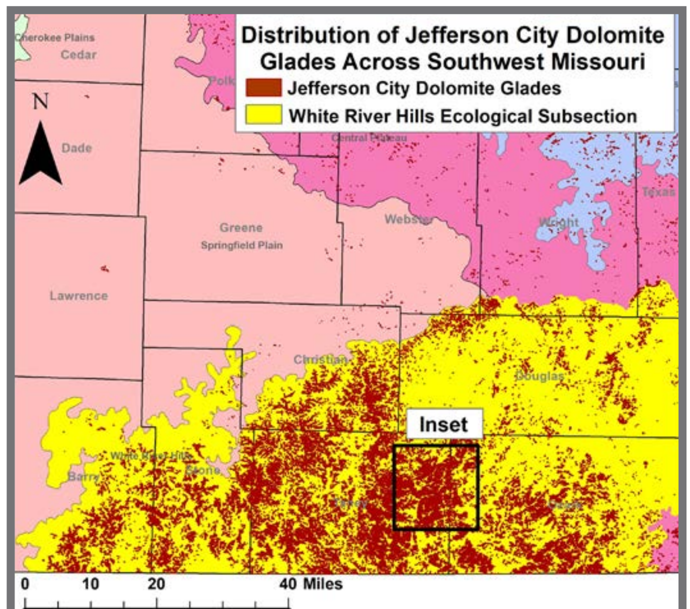

Figure 7-22. *Inset A from Figure 7-21 depicting dense concentrations of dolomite glades spanning nearly 100 miles across southwest Missouri. Note inset.*

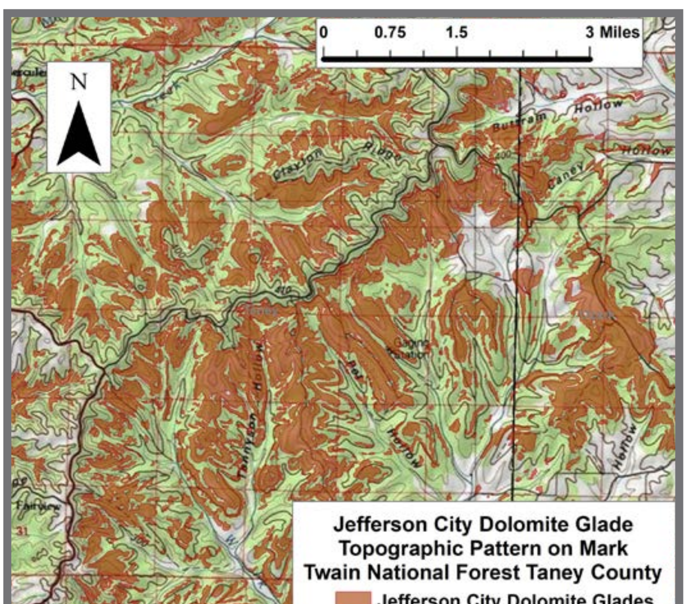

Figure 7-23. *Inset from Figure 7-22 is a portion of Missouri's densest area of glades along the Glade Top Trail in the Protem NE 7.5' quadrangle map, Taney County.*

Ralph Erickson mapped approximately 4,000 glades in this area in the early 1940s (Erickson et al., 1942). Other notable glade concentrations or arrays occur along the drainages and upper escarpments of the Gasconade, Osage and Pomme de Terre rivers. Elsewhere the distribution of glades corresponds to the broad geologic band of Ordovician rock formations.

Other large glade clusters (totaling 14,000 acres) occupy the dissected drainages of Osage, Gasconade, Meramec and Missouri river tributaries between Jefferson City and St. Charles. These glades are smaller and more widely spaced likely because the strata are thinner and occur at lower elevations.

TOPOGRAPHIC RELATIONSHIP TO DISTRIBUTION PATTERNS

The Jefferson City Dolomite is Missouri's most significant glade-producing formation. A brief discussion about the influence of past geologic history and climate might explain the origins and current glade patterns (and the origins of its distinctive flora and fauna). Along with the development of tallgrass prairie and savanna, glades likely emerged from the otherwise weathered and eroded thin soils following the drier and hotter xerothermic period 5,000 to 8,000 years ago. Thus, these Missouri glades may be relicts of a more widespread shallow bedrock layer, exposed prior to and during the xerothermic period.

The authors believe the important glade concentrations, or arrays, were likely once connected owing to the absence of the present-day accumulated soils of more mesic climate conditions and resulting in the present-day patterns observed. One must note that the current rocky Ozark soils situated between disconnected glade "islands" themselves range from a few inches to less than 2 feet. This may explain the similarities of distinctive flora distributed across a landscape of isolated glades, and the evolution of certain glade genera into distinct but fragmentary disjunctions (Yatskievych, 1999). The author's intent is to point out that the origins and affinities of Ozark flora make sense when explaining the genesis of once-widespread and connected glade-producing rock formations. The Jefferson City Dolomite illustrates this former connectedness across Missouri's topography.

Earlier authors assumed that most Missouri glades were habitats of southwestern exposure. This study verifies glades of various rock formations possess their own distinct topographic qualities of aspect, slope, elevation and topographic position. The patterns exhibited in Figure 7-23 are typical of the Jefferson City glades in the White River Hills region but differ elsewhere across Missouri.

LITHOLOGY, SHAPE AND SIZE

The Jefferson City Dolomite is a light brown to buff, finely crystalline to shaly dolomite (Fig. 7-27). The formation can vary locally to a shale, siltstone or sandstone with some chert present.

The chert of the Jefferson City is characteristically oolitic. The average thickness of the Jefferson City is approximately 200 feet, however thicknesses to 350 feet have been documented (Thompson, 1995). Near the base of the formation a prominent dolomite unit called the Quarry Ledge is present. This unit is gray to brown, massive bedded, burrowed dolomite which weathers to a characteristically pitted appearance (Fig. 7-28). The upper portion of the Jefferson City Dolomite (formerly considered the Cotter Dolomite) is a light gray to buff, dolomite to cherty dolomite.

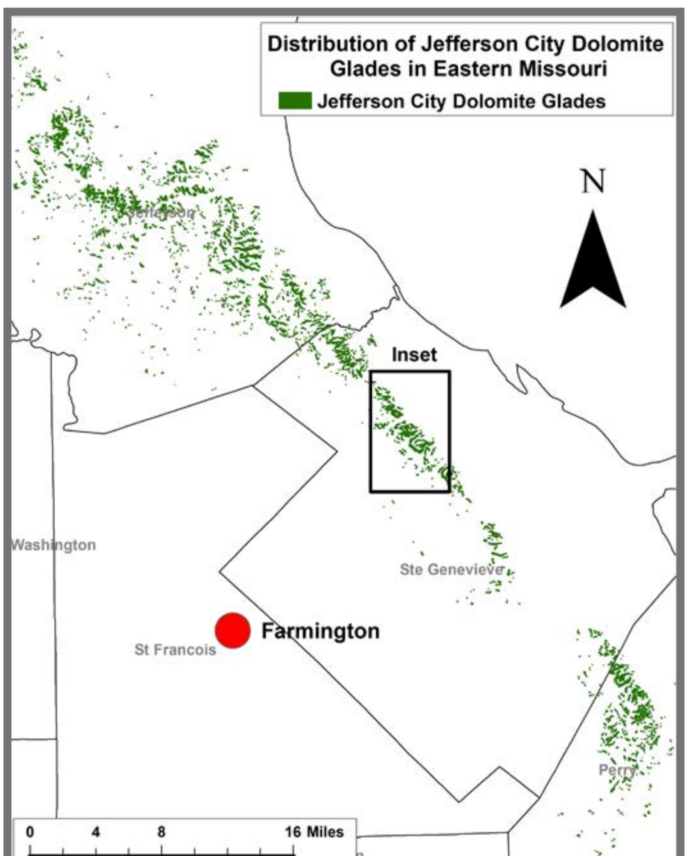

Figure 7-24. *Inset B from Figure 7-21. A significant area of Jefferson City glades stretches nearly 80 miles along an arc from Franklin, through Jefferson and Ste. Genevieve to Perry counties.*

Dolomite glades in the White River Hills are the largest of Missouri glades, with 31 greater than 200 acres and the largest more than 943 acres (Fig. 7-29). However, because of their proximity across the landscape, a mere 100 feet between them would connect three adjacent glades totaling 1,680 acres. These glades come in many unique shapes owing to the thickness of the Jefferson City distributed across the deeply dissected portion of the Ozark Plateau landscape and the White River and its tributaries that carved through it. The Jefferson City, which is more than 700 feet thick in places, is at the highest landscape position on the deeply dissected hills and knobs in the eastern one half of the White River Hills Ecological Subsection. Many glades descend into the valleys below because of the bedrock thickness, often extending across valley floors. As the formation is overlain by younger strata of the Springfield Plain in the proximity of Roaring River State Park, the glades occupy valley floors below the complex Mississippian-age units. Many large glades have very long perimeters, the longest at 54 miles (Fig. 7-29). An astounding 17,281 miles of total perimeter occur on these glades. Typically, they slope between 0 degrees across ridges and knobs to 30 degrees on hillslopes and 0 degrees to 15 degrees in the valley floors.

Figure 7-31 depicts aspect assigned to a cross section of 205 mapped glades of all sizes along Glade Top Trail in Taney County. Thirty-one large glades cover expanses of ridges and balds with aspects facing every direction. The graph also depicts aspect assigned to a cross section of 85 north and east-facing elongated ridges south

of the Cane Creek drainage just north of Glade Top Trail in Taney County. In contrast, the 250 glades centered in Spring Creek Gap Conservation Area near the Gasconade River (Maries County) sharply reveals their predominant southwest trending aspect.

In the White River Hills, the glade-producing formation is strongly influenced by a thickened Jefferson City Dolomite and reaches its maximum thickness of several hundred feet. When coupled with deeply cut stream erosion and elevation differences of 500 feet or more, the result is continuous, broad expanses of 1,000-foot-wide glades. Erosional patterns across the landscape left high conical hills capped in glades as well as concentric rings of glades banding the mid to lower elevations. Deeply dissected hills have ridges extending outward as much as 1 mile. Wide U-shaped glades of many sizes occupy their flanks. Where more isolated, these glades form the classic broad U-shaped convex shapes we often think of as traditional southwest-facing glades of the Ozarks. Shapes and aspect vary widely as shown in Figure 7-29. Conical hills of southwest Missouri produce rounded balds, concentric-midslope rings encircling hills, saddles and convex curves on ridge points (Fig. 7-29). Three area samples were chosen to illustrate the difference in glade orientation and directional aspect. The first was a selection of 205 glades across the northern section of the Taney 7.5′ quadrangle in Taney County. They occurred on the north and south side of an east-west 5-mile-long ridge capturing a mix of glades distributed equally across dissected ridges facing all directions. The second was a selection of 85 glades (totaling 885 acres) along a 5-mile-long stretch of dissected ridges facing north and east along Cane Creek in Taney County. Finally, 205 were mapped in the hills dissected by Cedar Creek and Paradise Valley around Spring Creek Gap Conservation Area in Maries County.

Comparing radial charts (Fig. 7-31), the Glade Top Trail sample reveals that aspect for 205 glades totaling approximately 2,000 acres is strongly oriented in all directions excepting a decrease of north-facing glades. However, if by choosing an area of nearly equal size where hills and ridges face north, the 85 selected Cane Creek glades (885 acres) are strongly oriented west, north and east. The authors can select any area within the White River Hills and demonstrate that aspect variations are determined by stream pattern orientation and concentrations of conical hills. In strong contrast, the glades centered in Spring Creek Gap in the Gasconade River drainage predominantly orient to south and west with few facing north to east.

Of the total 50,416 mapped glades, nearly 100 of them exist that are more than 100 acres. The mean size for the 50 largest is 270 acres. Taney County has more than 53,000 acres. Likewise, the Protem NE 7.5′ quadrangle has the largest density of glade acreage in Missouri, and the eastern U.S. with 10,288 acres and 900 miles of perimeter within a roughly 58-square-mile area, with one complex glade having a 44-mile perimeter. The sedimentary layering of the often thick, continuous Jefferson City bedding with interbedded layers of chert and sandstone results in patterns of rock ledge contours readily visible

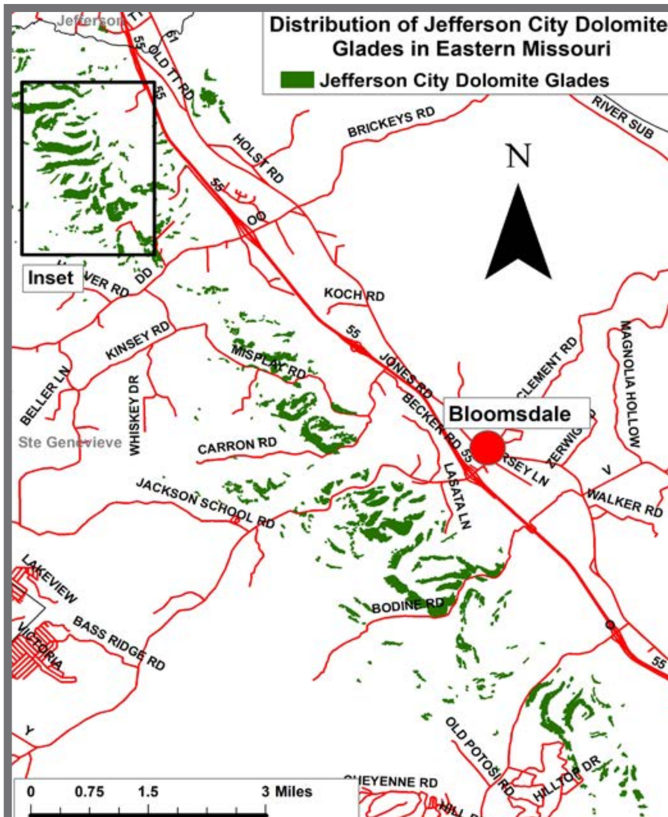

Figure 7-25. *Inset from Figure 7-24, east to west-trending ridges and valleys create zebra-like glade patterns in the Inner Ozark Border Subsection (Fig. 4-4) along the eastern flanks of the Ozark dome of eastern Missouri. Note inset for topographic patterns in Figure 7-26.*

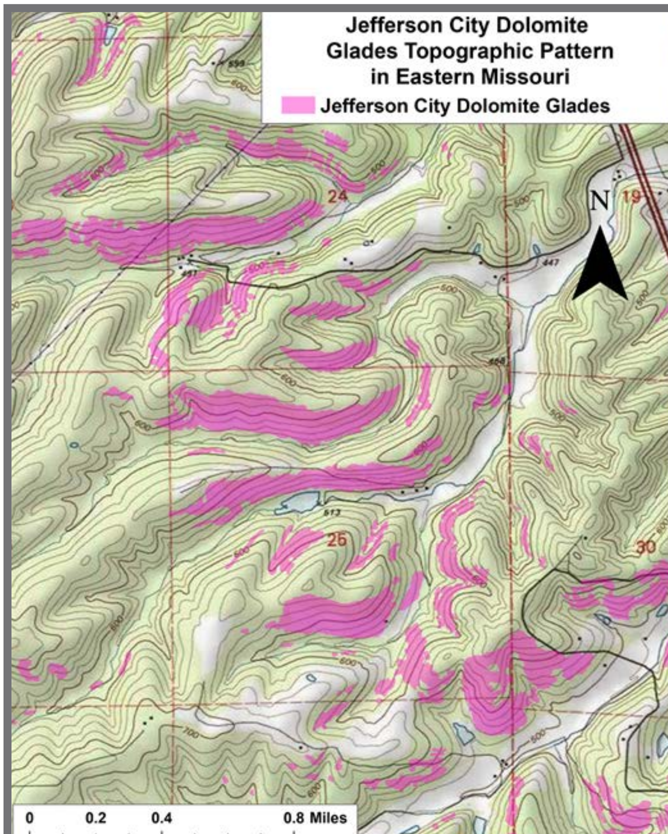

Figure 7-26. *Expands from inset in Figure 7-25 depicting glade pattern and topographic expression as influenced by east to west-trending ridges and valleys.*

Figure 7-27. *Finely crystalline Jefferson City Dolomite in Franklin County. MoDNR photo by Pierce.*

Figure 7-28. *Typical outcrop highlighting the burrowed and pitted appearance of the Jefferson City's Quarry Ledge Member, Ozark County. MoDNR photo by Pierce.*

on aerial images. On the ground, differences in weathering and erosion resistance in the formation layers results in alternating rock wall ledges (often 2-3 feet high) and level flat pavement. Here and there are thin blocks or slabs of dolomite flat stone, some three to five feet wide and often 5 to 10 inches thick. Smaller flagstones and chert fragments often litter the ground. Joint and solution fractures can lead to open natural trenches, often 10 feet deep, especially in the Glade Top Trail vicinity.

Centered near Hillsboro in Jefferson County, glades developed on the Jefferson City occur along a 25-mile-wide linear arc stretching from Gray's Summit to just west of Perryville in Perry County. These glades range from 15 acres to 74 acres. Their zebra-like pattern (Figs. 7-24 and 7-25) across the landscape is likely due to the complex drainage pattern of streams that align themselves parallel along the Ozark Border Subsection. Most are broadly rectangular approaching one-half mile in length and 300 to 400 feet wide, with slopes ranging from 10% to 30% (Fig. 7-26). An estimated 60% are generally oriented to the south with the remainder occurring on any aspect. Midslope glades near and north of Hillsboro tend toward being broad U-shaped glades wrapping around the terminus of ridge points.

More than 430 glades within three 12-square-mile areas were assigned aspects as displayed in the radial chart (Fig. 7-32). Unlike the glades in the White River region, nearly 180 miles to the southwest. Most of these glades trend south and west. Both the Festus (187 glades) and Victoria Glade (145 glades) areas occur in glade-dense Jefferson County. The Bloomsdale complex (99 glades) occurs in Ste. Genevieve County.

PUBLIC LAND LOCATIONS AND FUTURE PROTECTION OPPORTUNITIES

While it appears that the White River Hills Subsection glades are adequately protected (Table 7-4), conservation organizations should evaluate and consider protection of Jefferson City glades along the central and southern extent of the dense glade band to the southeast of Victoria Glade Conservation Area in Jefferson (Fig. 7-25), Ste. Genevieve, and Perry counties, and in the upper Deane Creek drainage of southeast Camden County.

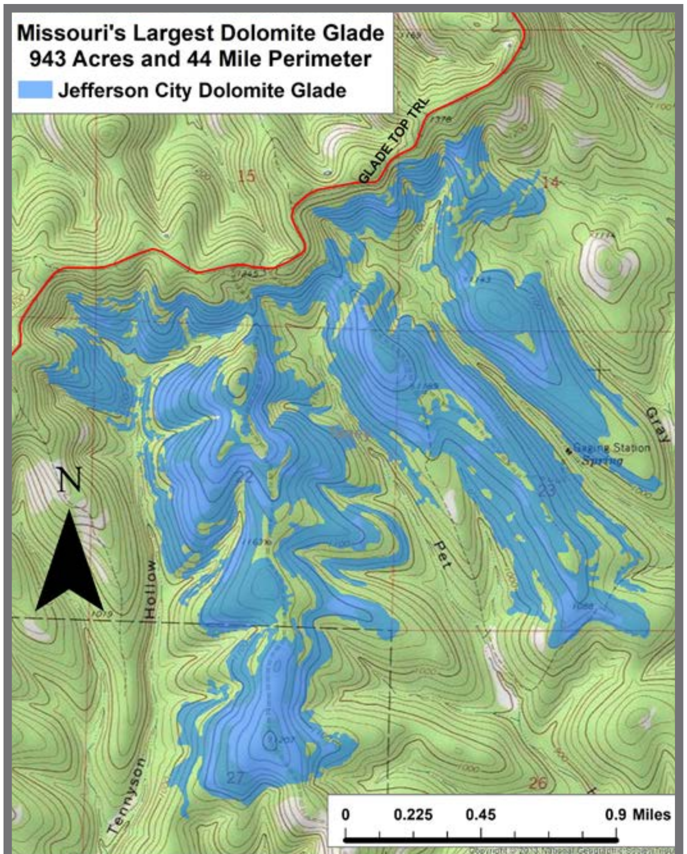

Figure 7-29. *943-acre Jefferson City glade complex containing more than 50 miles of glade boundary in Taney County.*

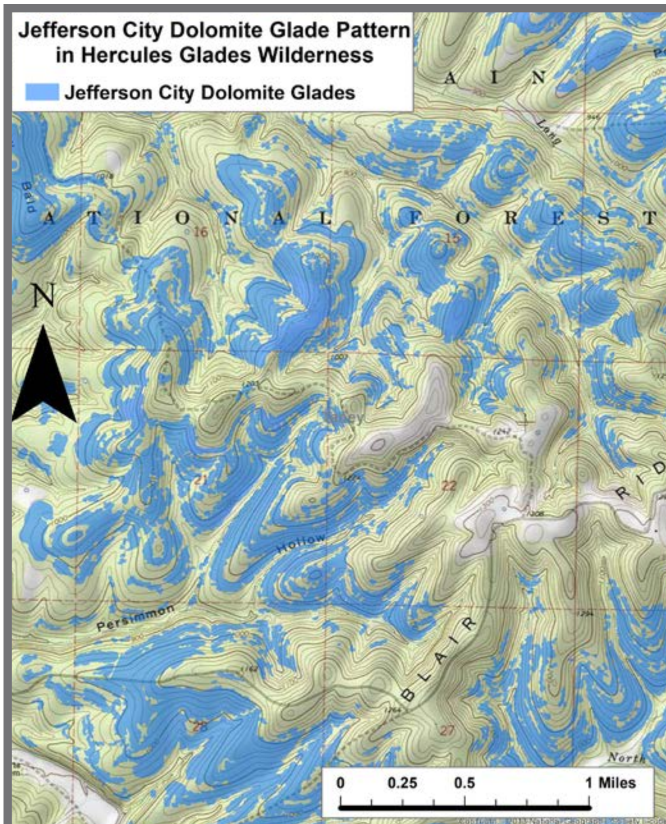

Figure 7-30. *Parallel lineaments cross dissected topography in Hercules Glades Wilderness in Taney County directly influencing patterns and shapes of glades.*

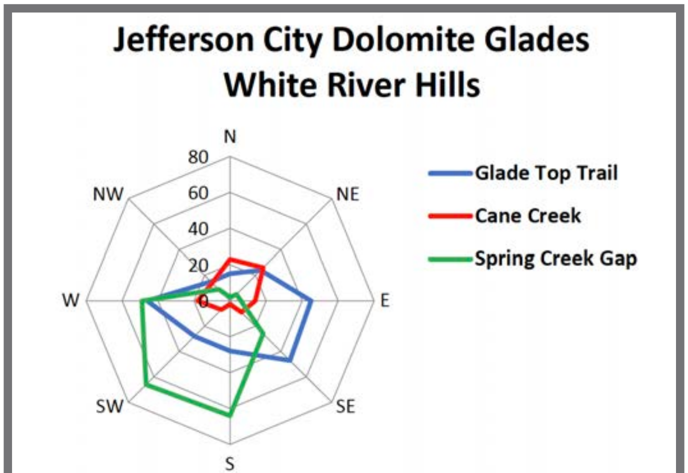

Figure 7-31. *Radial aspect chart for three Jefferson City Dolomite glade complexes.*

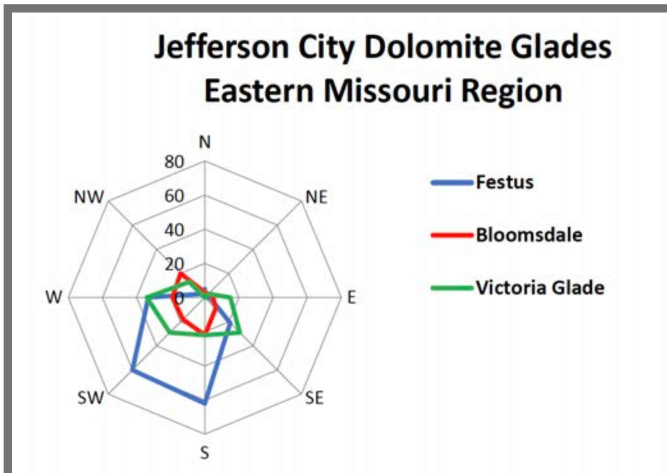

Figure 7-32. *Radial aspect chart for three Jefferson City glade complexes in eastern Missouri.*

Figure 7-33. *Victoria Glade Conservation Area, Jefferson County.*

Name of area	County	Number of glades	Total acres	Largest glade (acres)
Roaring River SP	Barry	36	662	263
Table Rock SP	Taney	20	146	48
Lake of the Ozarks SP	Miller/Camdenton	69	78	25
Pomme de Terre SP	Hickory	11	14	3
Truman Lake ML	Benton	99	117	11
Pomme de Terre ML	Hickory	29	22	3
Spring Creek Gap CA	Wright	157	238	19
Victoria Glade CA	Jefferson	10	93	36
Valley View Glades CA	Jefferson	12	106	40
Gist CA	Texas	228	184	11
Drury Mincy CA	Taney	168	639	104
Bull Shoals Lake ML	Taney	825	3,260	133
Caney Mountain CA	Ozark	223	536	54
MTNF	Southern Missouri	6,629	41,425	968
Shannon Ranch CA	Shannon	63	117	17
Ruth and Paul Henning CA	Taney	75	635	168
Ozark Mountain SP	Taney	59	726	176
Bryant Creek SP	Douglas	14	15	8
Total	16	8,727	49,013	

Table 7-4. *Lists of the most significant occurrences of Jefferson City Dolomite glades protected in Missouri state parks (SP), Missouri Department of Conservation management lands (ML), Missouri Department of Conservation areas (CA), and USFS national forest (NF) as of 2019.*

MIDDLE ORDOVICIAN-WHITEROCKIAN-AGE GLADE-PRODUCING FORMATIONS

The next three glade substrate types occur within the middle and upper Ordovician System. Glades from the St. Peter Sandstone, Joachim Dolomite (Joachim) and Plattin Group Limestone (Plattin) are distributed primarily in the Outer Ozark Border Subsection, a 20-mile-wide arc of dissected hills beginning in Boone County near Boonville north of the Missouri River then stretching eastward more than 100 miles through Jefferson City and Hermann to St. Louis. From St. Louis, this arc turns southward along the west side of the Mississippi River to Perry County. Numerous streams and small rivers incise the landscape through a variety of rock formations, resulting in perhaps the most diverse assemblages of glade types in the state.

ST. PETER SANDSTONE GLADES

Number of glades	1,563
Minimum size	0.01 acre
Maximum size	7.0 acres
Total acreage (sum)	894 acres
Mean size	0.6 acre
Maximum perimeter	1.1 miles
Total perimeter	249 miles
Mean perimeter	0.2 mile
Pattern density	Dense south of Hermann in Gasconade County, widespread in Montgomery and Warren counties, scattered elsewhere.
Classification – Terrestrial Natural Communities of Missouri (Nelson, 2010)	Sandstone glade natural community
Classification – International Ecological Classification Standard (Nature Serve, 2009)	Ozark Sandstone Glade

Table 7-5. *Statistical summary of St. Peter Sandstone glades.*

MISSOURI DISTRIBUTION

St. Peter Sandstone outcrops along the northern and eastern sides of the Ozarks, specifically in a narrow band that ranges from less than 1 mile to more than 10 miles wide. Outcrops are sporadic northwest of Montgomery County where some glades are associated with isolated paleo-sinkhole infills. From there, the band extends roughly 150 miles southeastward along the Missouri River and turns southward just west of St. Louis, continuing as irregular and localized outcrops through Scott County. An additional large area of St. Peter Sandstone is exposed at the surface along the axis of the Lincoln Fold in northeast Lincoln and southern Pike counties.

TOPOGRAPHIC RELATIONSHIP TO DISTRIBUTION PATTERNS

More than 1,560 glades occur in four complexes within the Ozark Border (Fig. 7-34). The first location contains approximately 350 densely packed glades (300 acres) in a 40-square-mile area situated immediately south of Hermann in Gasconade County. Figures 7-35 and 7-36 depict the expanded view of the inset in Figure 7-34. This is the only area where glades of St. Peter Sandstone occur in the Inner Ozark Border Subsection; here the St. Peter Sandstone crops out in the form of high rock ledges and cliffs along and above the 800-foot contour interval throughout the area. Many steep, sloping glades line the crest of these cuesta-like high cliffs and ledges (note zone of compact contour lines in Fig. 7-36) with a few forming in low saddles of high plateaus.

Seeger and Starbuck (2012) mapped the Fulton 30′ X 60′ quadrangle that includes a large portion of the St. Peter Sandstone Formation. Sandstone glades correlate well with the geologic accuracy presented in their study (Fig. 7-37). The aerial leaf-off image in Figure 7-38 clearly delineates the high contrast appearance of the glades associated with the St. Peter Sandstone shown in Figure 7-37.

The aspect chart (Fig. 7-39) highlights three glade complexes encompassing 9 square miles each. The Hermann sample set includes 132 glades situated immediately south of Hermann in Gasconade County (Fig. 7-35). The Bloomsdale sample set includes 119 glades centered near Bloomsdale in Ste. Genevieve County. The Danville sample set encompasses 99 glades centered 2 miles north of Big Spring in Montgomery County.

The second important glade area is widespread; north of the Missouri River in Warren and Montgomery counties where rugged dissected hills transition abruptly to level terrain of the Central Dissected Till Plains. Most of the glades occur on the higher midslope of moderately steep hills, mostly below 700 feet. The third notable area occurs some 60 miles to the southeast near Bloomsdale in Jefferson and Ste. Genevieve counties. Unlike the previous two described areas, these glades occur in an area of low hills where many occupy stream and headwater drainages, and low-relief ledges on hillslopes. Most glades are scattered between 450 to 600 feet in elevation.

LITHOLOGY, SHAPE AND SIZE

The St. Peter Sandstone is typically a well-sorted, friable, ultra-pure, fine-to medium-grained, quartzose sandstone with rounded, highly spherical and characteristically frosted grains. Bedding is indistinct, and the formation appears massive throughout. The rock is locally cross-bedded and ripple-marked. The formation is generally porous, permeable and mostly non-fossiliferous in Missouri.

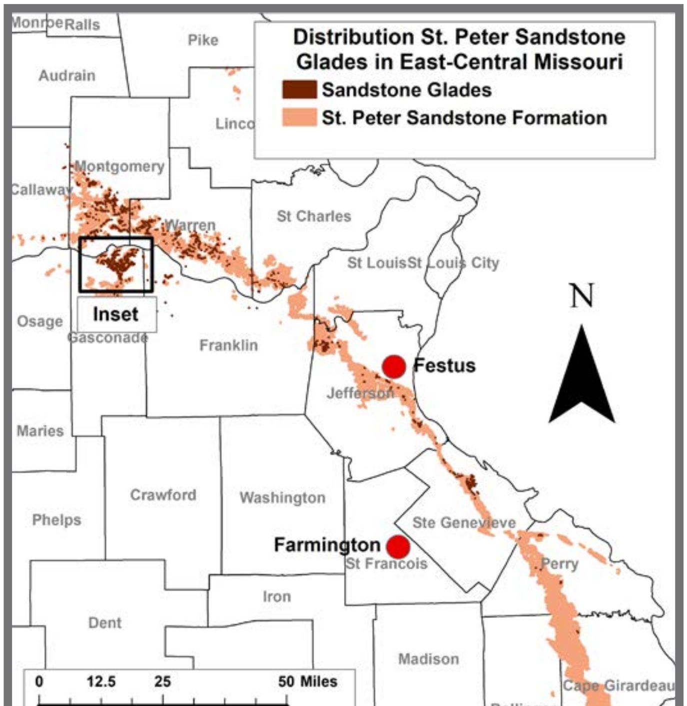

Figure 7-34. *Distribution of sandstone glades that occur along the St. Peter Sandstone in east-central Missouri. The formation forms a broad arc stretching more than 100 miles from Hermann in the northwest through Festus and down to Cape Girardeau and Scott counties.*

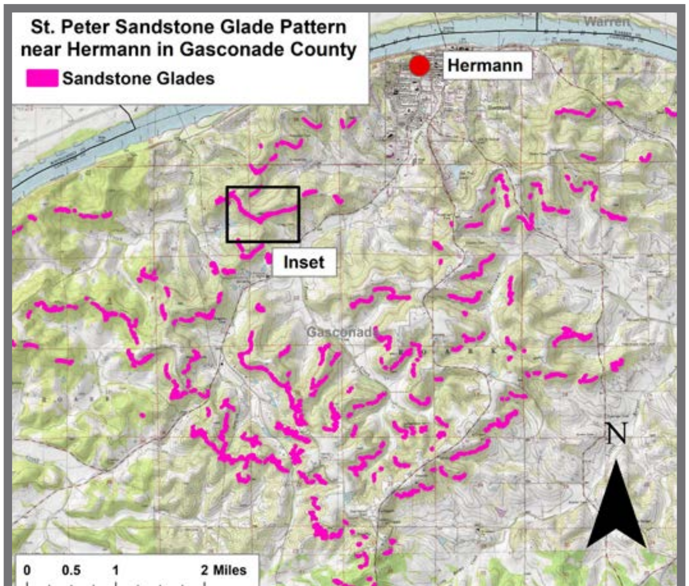

Figure 7-35. *Close-up of area topographic map (4 miles southwest of Hermann) from inset in Figure 7-34.*

Thickness varies from 10 feet to greater than 100 feet in some paleo sinkhole fills. On average, the formation ranges between 60 to 80 feet thick (Thompson, 1995). Because of the pure, uniform nature of the cemented sand that makes up this erosion-resistant formation, erosional downcutting through the formation results in upper slope escarpments of continuous cliffs and ledges, some 70 feet high and running for miles along dissected hillslopes. These cliffs are especially prominent in a 30-square-mile area immediately south of Hermann in Gasconade County. Where the formation dips into lower elevations of dissected valleys, glade outcrops are exposed along streams and drainages that contact the erosion-resistant bedrock.

The best displays in Missouri of the cuesta-like mid and upper slope steep ledges are those that nearly encircle the 300-foot-high hills and ridges to the south of Hermann in Gasconade County. Here, glades consistently follow the crest of cliffs found at the same elevation of mid and upper hillslopes. This results in a worm-like pattern of elongated, sinuous, often unbroken glades aligned along south and west-facing high slopes. The majority of the largest 50 glades occur in this region, averaging 3.3 acres compared to the 0.6-acre average for the total 1,513 glades elsewhere. Situated at the crest of the massive vertical sandstone cliffs and ledges, most of the Gasconade County glades are dangerously steep, sloping 10% to 45% then abruptly dropping off vertical cliffs and ledges.

Immediately across the Missouri River in Montgomery and Warren counties, this worm-like pattern on the landscape is gradually reduced to smaller glades isolated across a landscape of lower hills and knobs. Here, glades occur where the formation outcrops at lower elevations generally between 700 to 800 feet.

The small disjunct cluster of glades in Ste. Genevieve County occur near an elevation of 500 feet along the lower slopes of low hills and ridges where the St. Peter Sandstone contacts and dips below the overlying Joachim Dolomite. These glades form broken elongated chains that follow ridges oriented along a northwest to southeast line following the Outer Ozark Border. Unlike the main area of glades near Hermann, these glades occur on gentle slopes of 5% to 20% with few steep ledges or small cliffs.

These 1,563 glades encompass only 894 acres, resulting in a mean of 0.6 acres per glade and a total perimeter of 30 miles. The largest glade is only 7 acres with a perimeter of 1.1 miles.

PUBLIC LAND LOCATIONS AND FUTURE PROTECTION OPPORTUNITIES

In Jefferson County, LaBarque Creek Conservation Area and adjacent Don Robinson State Park protect 66 glades totaling 24 acres. Worthy of conservation efforts, more than 300 St. Peter Sandstone glades totaling 217 acres occupy a 20-square-mile area immediately south of Hermann in Gasconade County. Within this area, 40 glades totaling 58 acres occur in 1-square-mile alone.

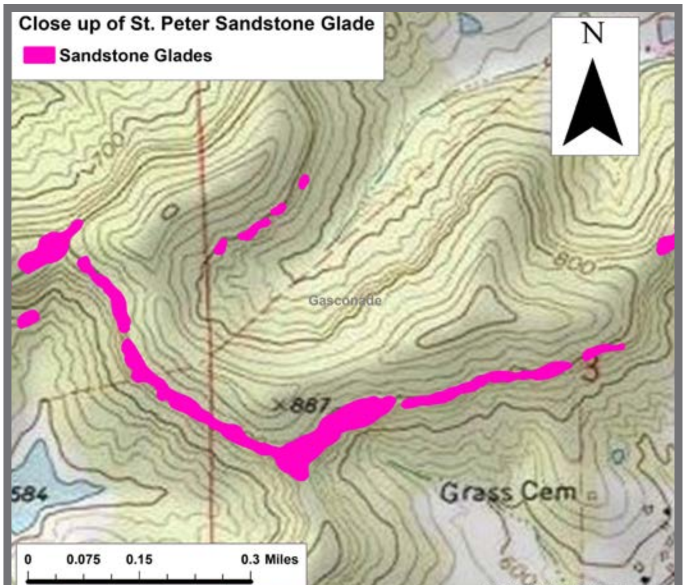

Figure 7-36. *Topographic map of glades from inset in Figure 7-35.*

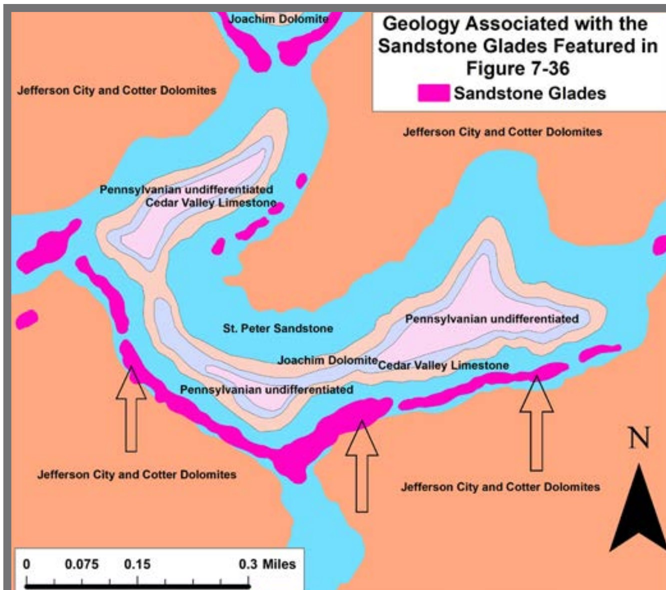

Figure 7-37. *Detailed geologic map for portion of region west of Hermann depicting glades (note arrows) superimposed on bedrock map highlighting the St. Peter Sandstone Formation.*

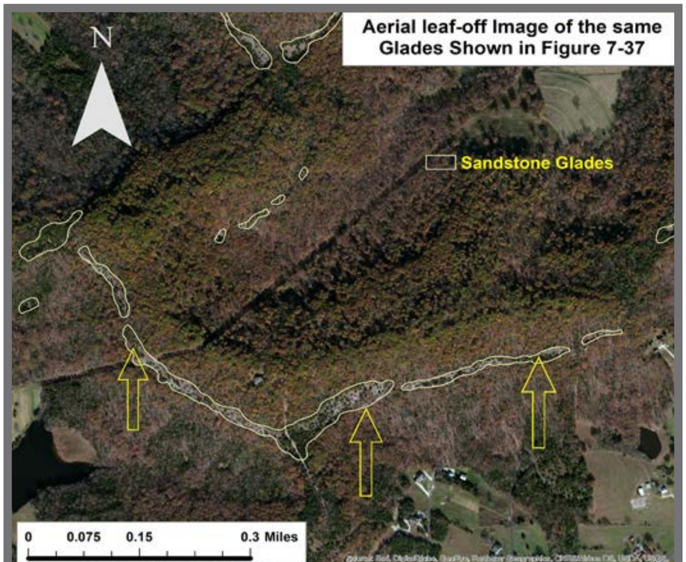

Figure 7-38. *Aerial leaf-off image denoting sandstone glades identified in Figure 7-37.*

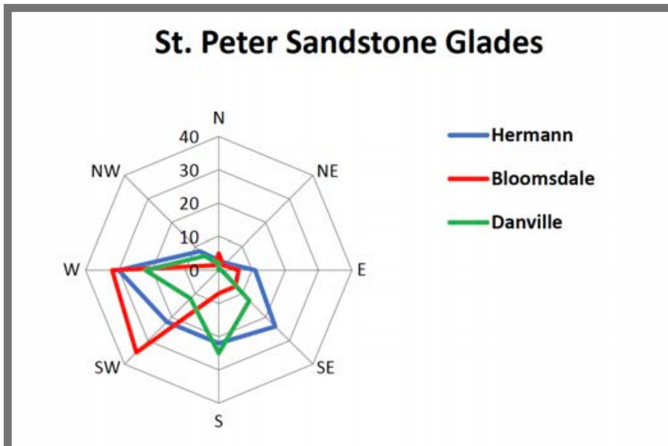

Figure 7-39. *Radial aspect chart of three separate St. Peter Sandstone glade complexes.*

Figure 7-40. *Sandstone glade four miles south of Hermann in Gasconade County.*

Figure 7-41. *Glade three miles west of Hermann in Gasconade County. Glade occurs on top of abrupt, near vertical cliff (on left) typical of glades in the region.*

ORDOVICIAN SERIES WHITEROCKIAN STAGE AND MOHAWKIAN STAGE GLADE-PRODUCING FORMATIONS

JOACHIM DOLOMITE GLADES

Number of glades	505
Minimum size	0.03 acre
Maximum size	15 acres
Total acreage (sum)	555 acres
Mean size	1.1 acres
Maximum perimeter	2.0 miles
Total perimeter	114 miles
Mean perimeter	0.2 mile
Pattern density	Scattered to widespread in isolated clusters
Classification – Terrestrial Natural Communities of Missouri (Nelson, 2010)	Dolomite glade natural community
Classification – International Ecological Classification Standard (Nature Serve, 2009)	Ozark Dolomite Glade

Table 7-6. *Statistical summary of Joachim Dolomite glades.*

MISSOURI DISTRIBUTION

The 505 mapped glades occur almost exclusively within the southeastern half of the Outer Ozark Border Subsection. This arc occurs in a narrow discontinuous band around the northeastern and eastern flanks of the Ozark structural uplift (Nigh and Schroeder, 2002). Due to the structural dip of geologic layers into the adjoining Illinois Basin in Ste. Genevieve County, three glade-producing geologic units (Plattin Group Limestone, Joachim Dolomite and St. Peter Sandstone) dominate this subsection along with the underlying Jefferson City Dolomite glades in the adjacent Inner Ozark Border Subsection. These Joachim glade bands occur in a narrow belt of deeply dissected hills ranging from 4 to 10 miles wide. The belt of Joachim glades stretches nearly 100 miles from southeastern Warren and St. Charles counties southeastward through Jefferson and Ste. Genevieve counties, ending in Perry County. Their density is locally widespread to scattered throughout the range.

Figure 7-42. *Glade within the Joachim located three miles southeast of Bloomsdale in Ste. Genevieve County. Note the light gray weathered rock slabs and layer cake-like shelves.*

TOPOGRAPHIC RELATIONSHIP TO DISTRIBUTION PATTERNS

Along the Missouri and Mississippi rivers west and south of St. Louis, entrenched streams dissect the landscape into rugged hills and deep valleys approaching 450 feet of relief. These rugged, steep slopes intersect and expose numerous bedrock layers producing a situation where Plattin Limestone and St. Peter Sandstone glades can occupy the same steep hill. In Jefferson County, Joachim glades occur at higher elevations between 600 to 900 feet. To the south in Ste. Genevieve County, these glades drop to lower elevations between 500 to 600 feet especially along the lower slopes of Beckett Hills, where 2 miles north of River aux Vases, the Joachim formation dips lower on the landscape. Joachim glades occur predominantly on south- and west-facing steep slopes (Fig. 7-45), but may be found on north to east aspects, in rare instances.

Figure 7-44 clearly depicts the dominant southwest aspect of glades analyzed in three separate areas across the overall glade distribution area. Some 77 glades along an escarpment ridge north of Sandy Creek in Jefferson County show a predominant southwest aspect. The 47 glades of the Festus complex in Jefferson County are oriented toward the south, while the 26 glades east of Sunset Lake along Interstate 55 in Ste. Genevieve County are strongly southwest facing.

LITHOLOGY, SHAPE AND SIZE

The Joachim Dolomite is predominantly a yellowish-brown shaley dolomite with interbedded limestone, sandstone and shale beds in the lower portion. This lower portion commonly has scattered quartz grains and mud cracks throughout. Where exposed, the yellowish-brown rock weathers gray. Except for a thin persistent bed near the middle of the unit, chert is absent from the Joachim. In Jefferson and Ste. Genevieve counties, the Joachim often

lies directly on top of the St. Peter Sandstone with both glade types in direct contact with each other. In Scott and Cape Girardeau counties, the Joachim Dolomite is exposed and has an average thickness of 175 feet, but thins to the north where the average thickness is approximately 50 feet in Ralls and Montgomery counties. While the Joachim occurs in Cape Girardeau and Scott counties, no glades were mapped south of Perry County.

Several weather-resistant ledges outcrop along contours in layer cake fashion, particularly at lower portions of the glades where interbedded sandstones and shales occur. Erosion and undercutting of weaker rock beneath these resistant layers often form hollow horizontal voids and pockets extending several feet into the slope under the ledge (Fig. 7-42). This contrasts with the massive Jefferson City and Gasconade dolomites with glades that form on broad steps and benches of well-defined ledges and flat slab rock. The thinner bedded Joachim glades form on ledges that are crumbly and interrupted with broken irregular flat slabs (some 6 feet long by 2 feet wide) and flagstone strewn over the glade surface. Seep areas often occur along the contact zone where the weathered Joachim Dolomite meets the underlying St. Peter Sandstone.

Most Joachim glades are generally elongated (maximum 2,500 feet long) and as much as 450 feet wide with somewhat irregular boundaries. In their northern extent many are circular to oblong with somewhat irregular boundaries. Most glades are somewhat crescent-shaped as they wrap around south-facing rounded hills. The majority occupy moderately steep hillsides sloping 10% to 40% and often extend more than 140 feet in relief from the crest to the bottom of the slope. Few glades occur on summits or ridge saddles. Of the 505 total mapped Joachim glades, 30% are 1 acre or larger. The largest is 15 acres with a 2-mile perimeter. The 50 largest glades total 262 acres and 34 perimeter miles for a mean size of 5.2 acres and 0.7-mile perimeter, respectively.

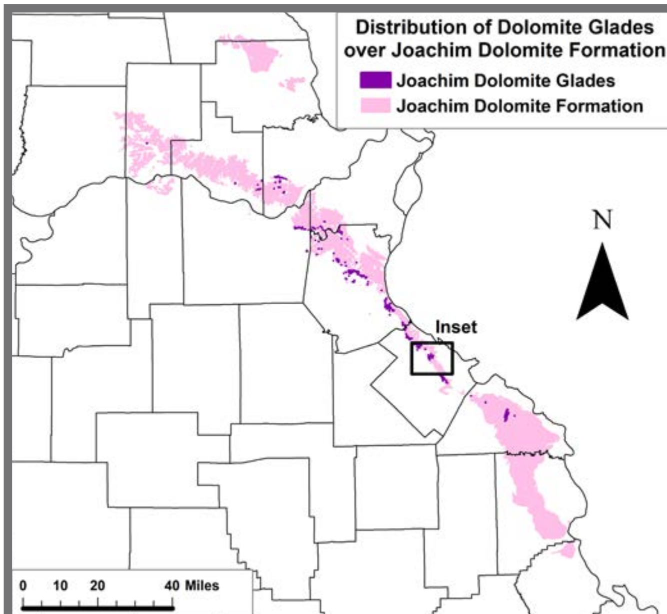

Figure 7-43. *Distribution of dolomite glades over the Joachim Dolomite.*

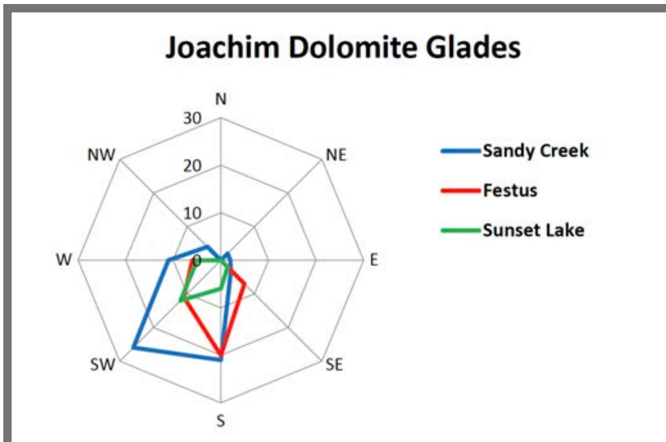

Figure 7-44. *Radial aspect chart of three Joachim Dolomite glade complexes.*

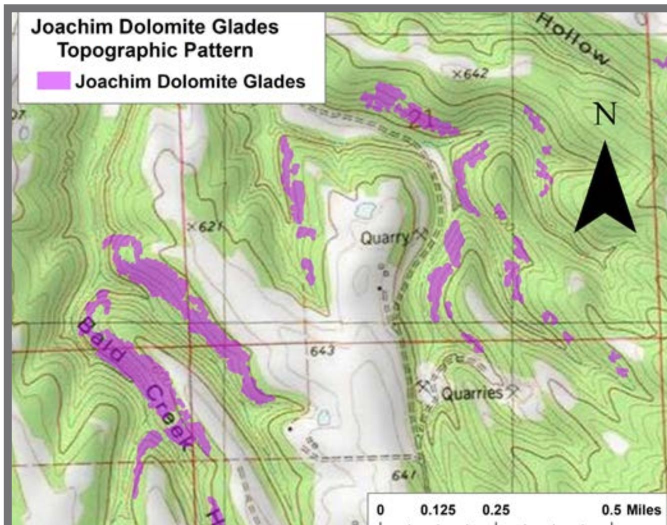

Figure 7-45. *Expanded view of inset in Figure 7-43 depicting west- and south-facing Joachim glades on relatively steep slopes 3 miles southeast of Bloomsdale in Ste. Genevieve County.*

Figure 7-46. *Weathered dolomite in the Joachim.*

PUBLIC LAND LOCATIONS AND FUTURE PROTECTION OPPORTUNITIES

A few small Joachim glades are protected on public lands. Conservation agencies should evaluate the remaining small complexes of large glades that remain.

Figure 7-47. *Sandstone glade in a scour valley contacts the Joachim Dolomite glade to the immediate left (defined by the grass border and rubble). Near Bloomsdale in Ste. Genevieve County.*

ORDOVICIAN- MOHAWKIAN-AGE GLADE-PRODUCING FORMATIONS

PLATTIN GROUP LIMESTONE GLADES

Number of glades	1,505
Minimum size	0.03 acre
Maximum size	11 acres
Total acreage (sum)	906 acres
Mean size	0.6 acre
Maximum perimeter	1.4 miles
Total perimeter	229 miles
Mean perimeter	0.2 mile
Pattern density	Scattered to widespread
Classification – Terrestrial Natural Communities of Missouri (Nelson, 2010)	Limestone glade natural community
Classification – International Ecological Classification Standard (Nature Serve, 2009)	Ozark Limestone Glade

Table 7-7. *Statistical summary of Plattin Group Limestone glades.*

Figure 7-48. *Plattin glade at Danville Glades Natural Area, Montgomery County.*

MISSOURI DISTRIBUTION

The Plattin Group consists of four geologic formations. Starting from the base upward are the Bloomsdale Limestone, Beckett Limestone, Hager Limestone and Macy Limestone. Geologists can identify these individual units in some areas south of the Missouri River. However, they are not individually identifiable everywhere and especially north of the Missouri River. Within the group, the Hager Limestone is the primary limestone glade-producer below the Missouri River.

The 1,541 Plattin Limestone glades occupy two distinct regions of Missouri: The Outer Ozark Border and Lincoln Hills of the Central Dissected Till Plains subsections. Some six to seven clusters have widespread densities in Warren, Montgomery, and Lincoln counties with other scattered to isolated glades distributed in Pike, Ralls, Callaway, Jefferson and Ste. Genevieve counties (Fig. 7-49). Glades occur throughout the Outer Ozark Border Subsection, extending some 130 miles from Callaway to Ste. Genevieve counties. The greatest extent and density of these glades occurs north of the Missouri River in Warren and Montgomery counties. The Plattin glades coexist in narrow bands with Joachim Dolomite and St. Peter Sandstone as part of the Outer Ozark Border. Plattin glades also occur in a disjunct region of typically Ordovician-age formations known as the Lincoln Hills.

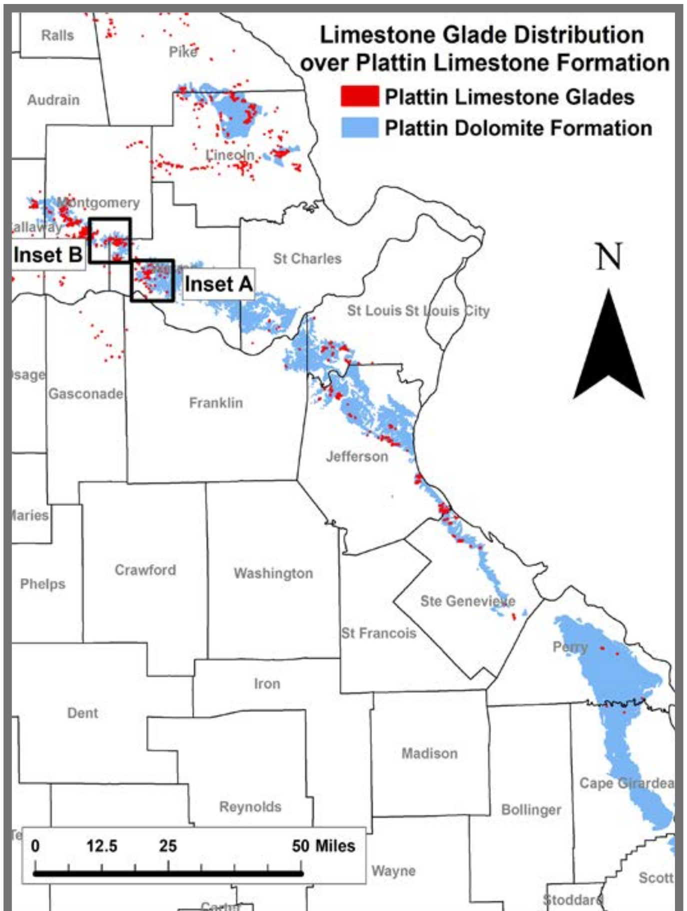

Figure 7-49. *Distribution of limestone glades over outcrop map of the Plattin Group across eastern Missouri.*

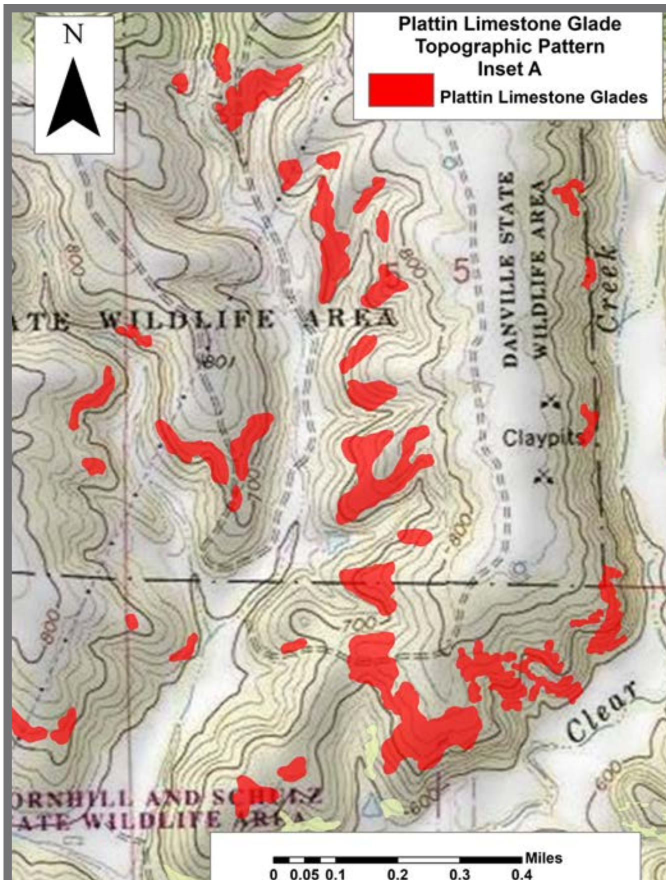

Figure 7-50. *Inset A from Figure 7-49. Plattin Limestone glade topographic pattern. Danville Glades Natural Area, Warren County*

TOPOGRAPHIC RELATIONSHIP TO DISTRIBUTION PATTERNS

Plattin glades follow along contours of mature dissected hills and valleys with 100 (Lincoln Hills) to 400-foot relief. Throughout their range, the glades occur consistently on steep slopes (10 degrees to 45 degrees) between 600 and 800 feet in elevation but drop between 450 to 600 feet elevation in Ste. Genevieve County. Figure 7-50 indicates Plattin glades are predominantly south and west facing (Fig. 7-52) with a few areas facing northward where exposed along deep open valleys (Fig. 7-51). Many glades are positioned at the end points or nose of narrow ridges, exposed side slopes and upper shoulders, often leveling out on flats. Some glades occur in the saddles of extremely narrow ridges flanked on both sides of the ridge by open valley streams. In some extended valleys, glades occupy nearly every steep south-facing exposed ridge forming isolated chains along valleys. In Lincoln County, Plattin Limestone glades occur in gently dissected upland drainages and low-relief valleys of plains with a slope of 5 degrees to 15 degrees.

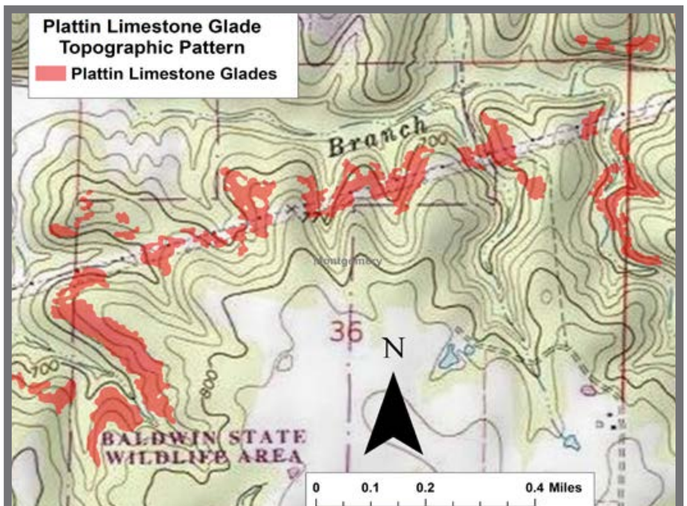

Figure 7-51. *Inset B from Figure 7-49 depicts topographic pattern, Montgomery and Warren counties.*

Figure 7-52 depicts a 12-square-mile area near Graham Cave State Park and Danville Glades Natural Area in Montgomery County that contains 91 glades. The majority are oriented south to west to north. The 57 glades centered 2 miles east-northeast of Pinnacle Lake in Warren County face southwest. The 60 glades analyzed 2 miles southeast of Eolia in Lincoln County centered in Sheldon Creek face south.

LITHOLOGY, SHAPE AND SIZE

The Plattin Group consists of several light to dark gray to tan, finely crystalline to micritic (sublithographic) limestone units with minor intercalated shales. This intercalation results in weathering to a crumbly, flaky texture of solid rock layers and limestone flagstone scattered about most glades.

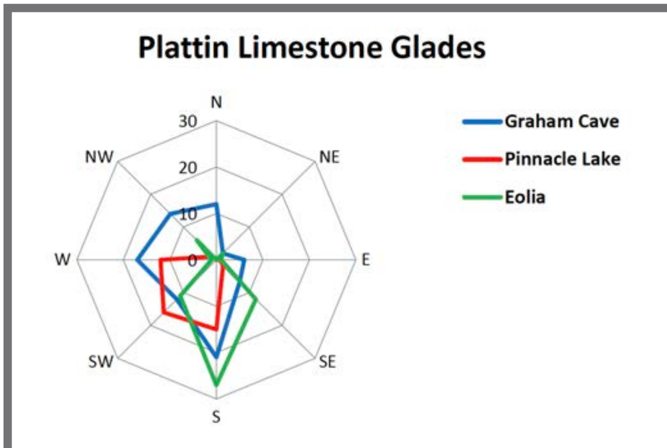

Figure 7-52. *Radial aspect chart for the Plattin Limestone glades.*

The Bloomsdale Limestone is a 5-foot to 10-foot-thick, brown to dark chocolate brown, partially oolitic, sublithographic limestone with alternating thin blue-gray shales and dolomite layers. The top of the Bloomsdale is marked by a green shale layer called the Establishment Shale Member. Overlying the Establishment Shale Member is the Beckett Limestone. This unit is a highly burrowed, light-gray, calcareous mudstone that ranges from 25 feet to 125 feet thick. The unit is the thickest of the four Plattin Group formations with its greatest thickness in southeast Missouri, then thinning northward. Burrows typically comprise greater than 50% of the rock mass and when unweathered, are filled with a light brown, coarsely crystalline limestone. When weathered, the burrows within the Beckett Limestone give the unit the appearance of a sponge. The Hager Limestone is a light-gray, massive, unburrowed, micritic limestone. It is thinner than the other formations, averaging between 10 feet to 15 feet; however, its massive nature leads to its prominence in outcrop formation as well as being the primary glade-producing formation of the group. The Macy Limestone ranges from 25 feet to 40 feet thick and is like the burrowed, gray Beckett Limestone except for the presence of potassium bentonite (volcanic ash) beds. The top of the Macy Limestone; and thus, the Plattin Group lies directly below a 6-inch-thick layer of volcanic ash called the Deicke Potassium Bentonite Bed.

The larger clusters of Plattin glades in Montgomery County (Danville Glades Natural Area) have somewhat elongated shapes with irregular, ragged boundaries, often appearing like variably sized splotches on the landscape. In Montgomery and Lincoln counties, the more widely scattered glades are smaller and appear circular to oblong with somewhat irregular boundaries. To the southeast in Jefferson and Ste. Genevieve counties, a few localized, isolated glade clusters have more elongated and somewhat crescent-shaped glades.

Glades are relatively small with a mean average of 0.6 acres. The largest is 11 acres, and longest perimeter 1.4 miles. The top 50 largest glades total 222 acres with a mean of 4.4 acres. These 50 glades total 33 perimeter miles.

Figure 7-53. *Table and pedestal formation (sometimes called hoodoos) on a Plattin Group Limestone glade in Danville Glades Natural Area, three miles southwest of New Florence, Montgomery County.*

PUBLIC LAND LOCATIONS AND FUTURE PROTECTION OPPORTUNITIES

Danville Glades Natural Area, Montgomery County protects 70 glades totaling 109 acres in the core of the primary Plattin Group Limestone glades distribution. More than 200 Plattin glades occur within a 5-mile radius of the natural area. Eighteen of the top 50 largest glades (nearly 40%) occur in this vicinity. Other Plattin Limestone glades occur at Little Lost Creek and Young conservation areas, and Graham Cave and Castlewood state parks.

Chapter 8. Mississippian-Age Glade-Producing Formations

Mississippian-age formations are divided into four series: Kinderhook, Osagean, Meramecian and Chesterian. More than 40 formations or geologic units occur within them. Of these, the following are grouped together as glade-producing geologic units:

1. Compton and Pierson complex includes Reeds Spring Formation and Sedalia Formation limestone glades.
2. Grand Falls Chert glades.
3. Burlington and Keokuk limestone glades.

KINDERHOOKIAN-OSAGEAN LIMESTONES

In most of southwest Missouri, the Compton Limestone consists of 5 to 50 feet of limestone and overlies the Ordovician-age Jefferson City Dolomite. Overlying the Compton Limestone is the Sedalia Formation (northern areas only) and the Northview Formation, a shale and siltstone unit. Above the Northview is the Pierson Limestone (if present). The Reeds Spring Formation, which consists of as much as 100 feet of very cherty limestone, overlies the Pierson. At its northern extent the chert content lessens, and the Reeds Spring is indistinguishable from the overlying Elsey Formation. The Burlington and Keokuk limestone, by far the most widespread and thickest Mississippian-age unit in the region, overlies the Elsey Formation and forms the bedrock surface throughout the eastern portion of the Springfield Plateau. The uppermost of the Osagean-age bedrock units is the Lower Warsaw Formation. In Southwestern Missouri this unit is a coarse-grained limestone like the Burlington and Keokuk formations and comprises the uppermost bedrock unit in the western portion of the Springfield Plateau.

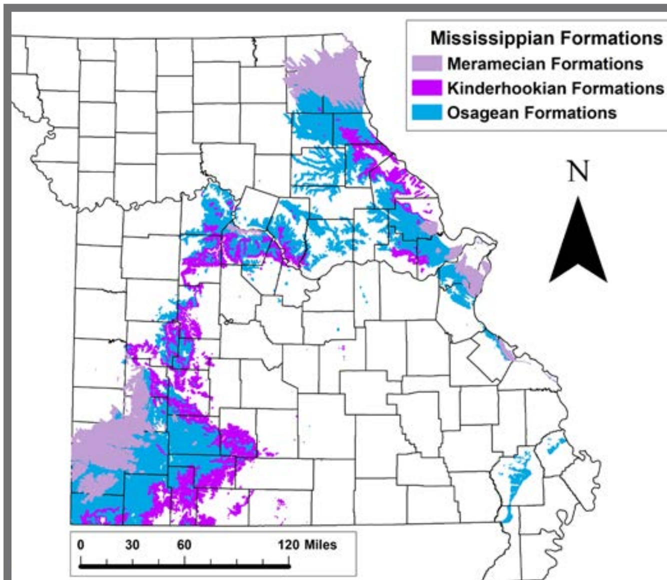

Figure 8-1. *Distribution of Mississippian formations.*

The geologic units of the Kinderhookian and Osagean series are early Carboniferous system (Mississippian subsystem) in age. Mississippian geologic units border the outer Ozark Plateau with the broadest zone in southwestern Missouri occupying the Springfield Plain, Elk River Hills, and western Osage River Hills subsections. The Mississippian-age units also border the northern Ozark Plateau across the Prairie Ozark Border, Mississippi River Hills, and portions of the Outer Ozark Border subsections. The primary limestone glade-producing formations of the northern Ozark Plateau are the Compton (Kinderhookian) and Pierson (Osagean) limestones with lesser references made to Sedalia and general assignments to Kinderhookian-Mississippian limestones. Northview Shale (White River and western Osage River Hills) overlies the Compton Limestone while Chattanooga Shale underlies it in McDonald County. The Northview and Chattanooga Shale formations are grouped separately under shales.

Much uncertainty and difficulty exist in separately describing the above geologic units in the field. More than 50% of the 48 EORs for limestone glades make little attempt to identify the specific geologic unit. Bedrock mappers often group the Compton and Pierson limestones as a single mapping unit because of the lithological similarities, high variability in their thickness and difficulty in field identification.

COMPTON AND PIERSON (COMPLEX) LIMESTONE GLADES

Number of glades	5,277
Minimum size	0.02 acre
Maximum size	24 acres
Total acreage (sum)	5,208 acres
Mean size	1.0 acre
Maximum perimeter	1.9 miles
Total perimeter	1,059 miles
Mean perimeter	0.2 mile
Pattern density	Widespread in White River Hills Subsection. Widespread, gradually tapering to scattered then isolated in Elk River Hills Subsection
Classification – Terrestrial Natural Communities of Missouri (Nelson, 2010)	Limestone glade natural community
Classification – International Ecological Classification Standard (Nature Serve, 2009)	Ozark Limestone Glade

Table 8-1. *Statistical summary of Compton and Pierson limestone glades.*

MISSOURI DISTRIBUTION

The 5,277 Compton and Pierson limestone glades are distributed in three primary ecological subsections: White River Hills, Elk River Hills and upper Osage River Hills, along with one small area of glades occurring in the Lincoln Hills Subsection in northwest Lincoln County. The first primary subsection is the Springfield Plateau of southwestern Missouri. It is a high-level plateau of Mississippian-age limestone strata, including the Compton and Pierson formations, and averaging between 1,000 feet to 1,700 feet in elevation. This broad, level plateau stretches from the southwest corner of Missouri northward along the Kansas-Oklahoma border to Joplin where the elevation is nearly 1,000 feet. From there, its plateau rises upward and eastward to Webster County reaching nearly 1,700 feet in elevation. Along the southern boundary of the plateau, in a line roughly stretching from Cassville northeastward to Sparta, Mansfield and Norwood, the plateau abruptly descends into the hills and breaks.

Figure 8-2. *Compton and Pierson limestone glade capping hilltop of steep ridge located 3 miles northwest of Shell Knob in Barry County.*

This abrupt steep slope along the edge of the plateau is known as the Eureka Springs Escarpment (also known as the Burlington Escarpment) and represents the boundary of the White River Hills Ecological Subsection to the south. The White River and its tributaries cut into the plateau, removing the upper Mississippian limestone strata and uncovering the Ordovician-age Jefferson City Dolomite, thus creating a landscape of rugged knobs, hills, and deep valleys. The dendritic drainage patterns resulting from stream and river downcutting left elevated and extended ridges, isolated knobs and hilltops where the Compton and Pierson formations remain at the highest elevations (Fig. 8-5). The greatest extent and concentrations of limestone glades from these formations occur throughout the highest hills and breaks, gradually disappearing southward and eastward. More than 3,500 (64%) of Compton and Pierson limestone glades occur in the White River Hills (Fig. 8-4). Their density is widespread throughout, but gradually becomes scattered to the south and east.

A second extensive region (1,550 or 29%) of Compton and Pierson limestone glades occurs throughout the hills of the Elk River and Big Sugar Creek drainages in the Elk River Hills Subsection of Southwest Missouri, mainly in southwestern McDonald County (Fig. 8-4). Density is widespread, but gradually becomes scattered to the west. The third region encompasses more than 140 Compton and Pierson limestone glades are scattered where the Pomme de Terre River drainage carves into the Springfield Plateau immediately west of Pomme de Terre Lake in Hickory County.

TOPOGRAPHIC RELATIONSHIP TO DISTRIBUTION PATTERNS

Missouri's most concentrated area of Compton and Pierson limestone glades occur along the upper shoulders of high sinuous ridges and on tabletop hills extending southward from the Eureka Springs Escarpment. The glades are distributed in the upper headwaters of the highest hills along the dendritic-shaped streams and rivers and mimic the contact between the Mississippian-age limestone and Ordovician-age dolomite strata beneath the plateau. Relief is generally 400 feet to 600 feet in the deepest dissected hills and breaks.

Glades associated with the higher dissected portion of the White River Hills tend to be more pronounced where they are overlapping and cap Jefferson City Dolomite glades (Fig. 8-5). The largest glades occur on high mountain knobs, balds, and saddles of extended high ridges and along the escarpment. Though the Compton and Pierson are combined, it appears the Compton Limestone is most prominent where Mississippian-age strata contact Ordovician-age dolomites. A few limestone glades occur at an elevation of 1,700 feet in Wright County, just 70 feet lower than the highest point in Missouri. In general, the glades occur between 1,100 feet to 1,600 feet in elevation throughout the state.

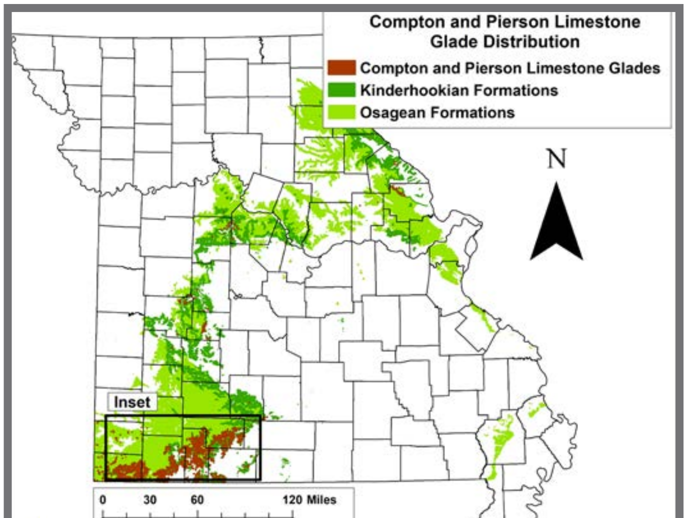

Figure 8-3. *Distribution of Compton and Pierson glades across Missouri. Note inset.*

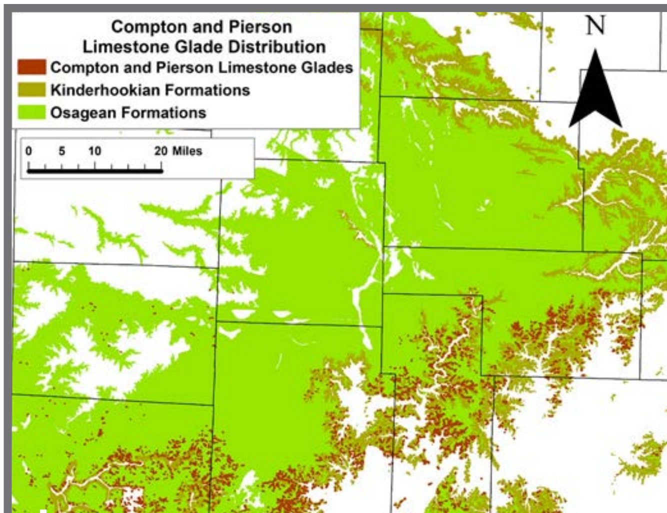

Figure 8-4. *Inset from Figure 8-3 depicts extent of glades (in brown) along the southern extent of the Osagean formations.*

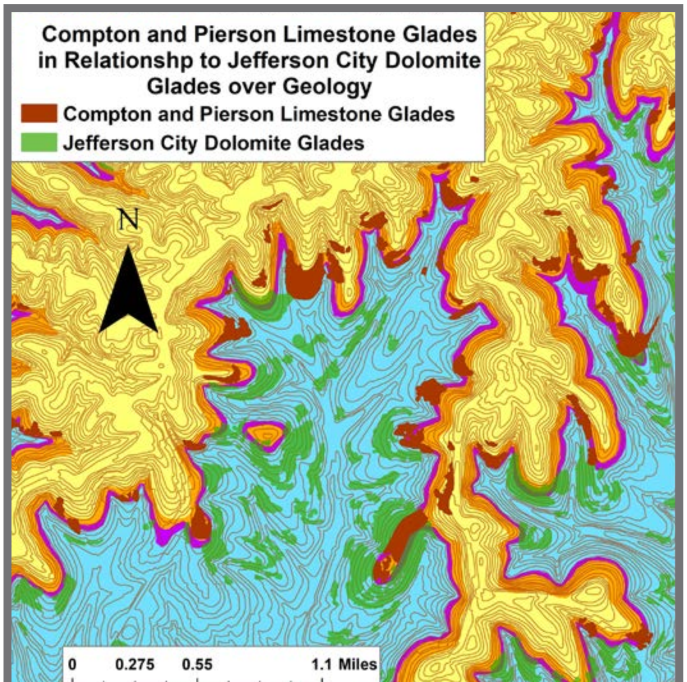

Figure 8-5. *Compton and Pierson limestone glade distribution in relation to Jefferson City Dolomite glades in the White River Hills. Note from contours that Mississippian formations (yellow, orange, violet) overlay Ordovician formations (light blue).*

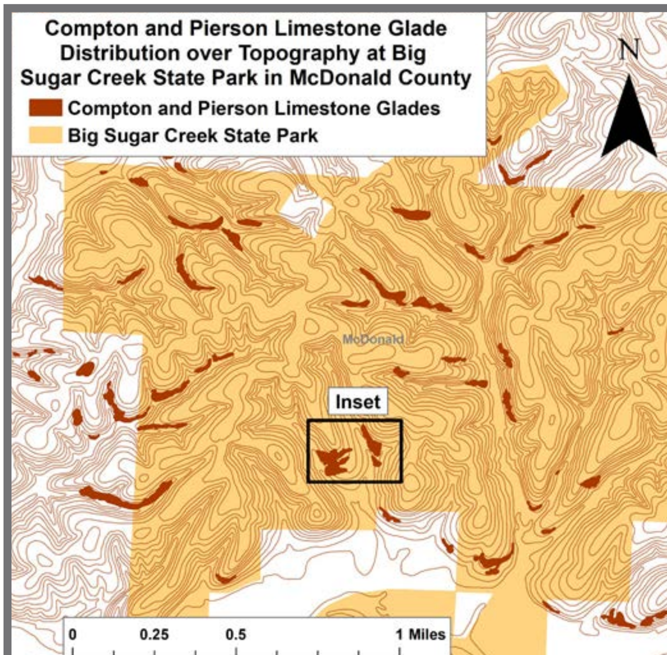

Figure 8-6. *Narrow banding of Compton and Pierson glades occurs on south to west-facing steep slopes of deeply dissected hills, here shown in the Big Sugar Creek drainage of Big Sugar Creek State Park in McDonald County. Note inset for reference to glade photographs.*

In contrast, Compton and Pierson limestone glades of the Elk River Hills Subsection (Fig. 8-6), while numerous, occur as narrow bands along south- and west-facing side slopes and in valleys of dissected hills. Their position on the landscape often coincides with exposures of Chattanooga Shale. In the Elk River Hills Subsection, it appears the Pierson Limestone is the more prominent glade-producer with glades occurring at elevations between 950 feet to 1,200 feet. The small group of glades near Pomme de Terre Lake occur between 850 feet and 975 feet in elevation.

A small cluster of glades occurs in northwestern Lincoln County, known as the Highway Z prairie. Pierce, Nelson and Trevor Ellis, on a site visit, determined the substrate to be Sedalia limestone belonging to the Compton and Pierson formations.

LITHOLOGY, SHAPE AND SIZE

The Compton is a finely crystalline to micritic limestone with crinodial fragments. It is parted with thin shale partings and a slabby appearance when weathered. The unit can be locally dolomitic in southwestern Missouri, and when so is typically brown and massive. Also here, the Compton can contain bluish to black cherts and it makes up the base of the Choteau Group that underlies the Sedalia and Northview formations. However, in east-central Missouri, the Choteau is composed entirely of Compton. The overlying Pierson Limestone is a medium to massive dolomitic limestone as much as 40 feet thick, primarily found in western and southwestern Missouri (Thompson, 1995). The lithology of the Compton and Pierson units is similar, thus when the Sedalia or Northview formations are absent, the units may be hard to distinguish in the field and combined for mapping purposes.

Figure 8-7. *Compton and Pierson limestone glade shown in Figure 8-6 inset. Glade is located at Big Sugar Creek State Park in McDonald County.*

Compton and Pierson limestone glade shapes are highly variable, depending on the position and thickness of the underlying strata, location on hillslopes or hilltops, and on the topography as shaped by erosion patterns. In the White River Hills the glades are generally no more than 150 feet thick. Thus, most of the glades are less than 200 feet to 300 feet wide, descending 100 feet or less in relief. However, since the formation is relatively thick, unbroken and resistant to erosion, it tends to follow equal elevation contours on hillsides that dissect the layering. Along the exposed strata, glades tend to occur along west, south and east aspects with a ledge (often 10 feet high) along sloping perimeters of the glade. Glade shapes are often linear-elongated, crescent-shaped (or half-moons) with many glades one-quarter to one-half mile long, especially in the Elk River drainage in extreme southwest Missouri. If the Compton and Pierson limestones occur at the top of a narrow ridge, the glade often takes the shape of a flat horseshoe or saddle hourglass (Fig. 8-11), with crescent borders between the end points. Several form double crescents, one atop the other. On exposed hills and knobs, the glades form a capped circle with a donut island of wooded chert float. As above, a high ledge forms the outer rim of the glade circling the hill. However, some circles are not complete and a form C-shaped crescent with the gap generally facing northward. The larger glades occur within the White River Hills Subsection. The 50 largest glades total 557 acres with a mean of 11 acres and total perimeter of 54 miles. The largest glade, at 31 acres, is 400 feet wide by 4,000 feet long with a 2.4-mile perimeter. Many of these glades cap hilltops that are flat to gently sloping as shown in the photograph in Figure 8-2.

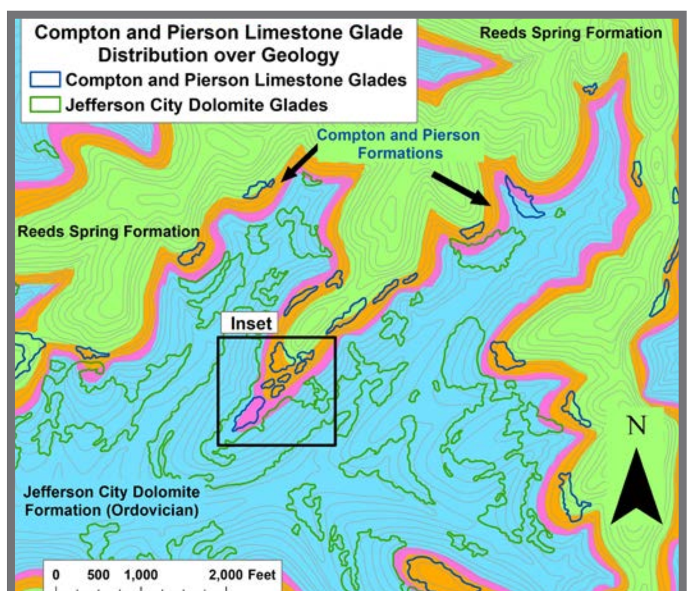

Figure 8-8. *Compton and Pierson glades mapped over Mississippian-age formations.*

Many Compton and Pierson limestone glades are directly associated with and continuous with the glades of the Jefferson City Dolomite beneath it (Fig. 8-8). The ledge located near the base of the Compton Limestone often delineates the boundary between the two glade types.

In the Elk River Hills, the Compton and Pierson limestone is much thinner. This restricts glade size with the majority consisting of narrow linear to narrow crescent shapes no wider than 100 feet and averaging 200 feet to 400 feet long with a maximum of 1,000 feet. The glades in the Elk River Hills typically occur at elevations between 900 feet and 1,050 feet. Their mean size is 0.5 acres as compared to 10 acres for those in the White River Hills. Glade slopes range from 15 to 45 degrees on hillslopes and 0 degrees to 15 degrees on ridgetops and saddles. The total perimeter of the largest 50 glades in the White River Hills is 54 acres while only 26 acres in the Elk River Hills.

In Figure 8-10, the directional radial aspect chart indicates most glades are oriented south and west. Nearly all the 61 glades at the Big Sugar Creek location in McDonald County face due south. Most of the 138 glades centered around Butler Hollow Natural Area in Barry County occupy steep southwest-facing hillslopes. The 96 glades near Reeds Spring in Stone County have a predominant southwest aspect. A significant number of glades in the White River Hills are excluded from the count because they occur on nearly level hilltops and ridges.

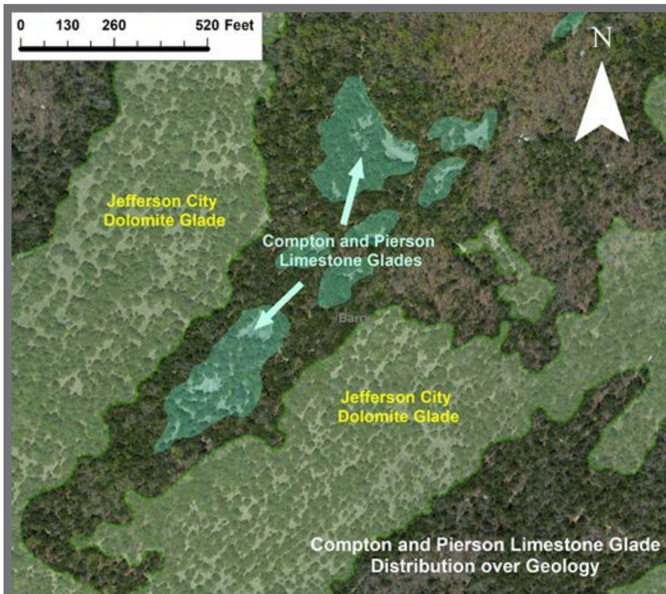

Figure 8-9. *Inset from Figure 8-8 reveals and validates limestone glades (denoted here as a smoother texture lighter gray).*

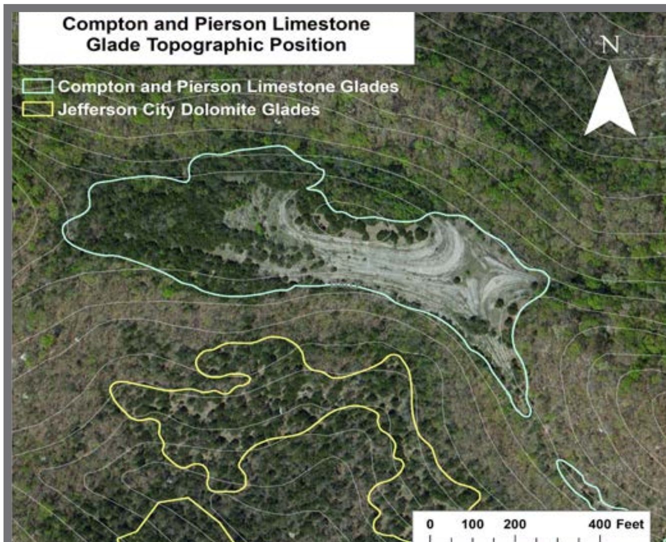

Figure 8-11. *Irregular hourglass-shaped Compton and Pierson limestone glade formed in a ridge saddle in Barry County.*

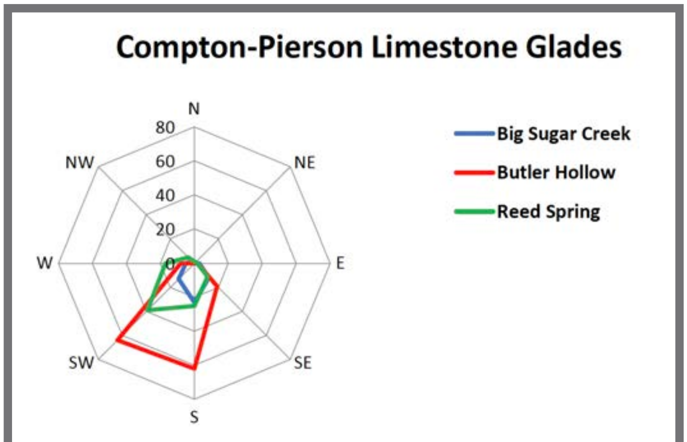

Figure 8-10. *Radial aspect chart for three areas located in southwest Missouri.*

PUBLIC LAND LOCATIONS AND FUTURE PROTECTION OPPORTUNITIES

Approximately 24% of the total 5,277 acres of Compton and Pierson glades are protected on public lands (Table 8-2).

Name of area	Number of glades	Total acres	Largest glade (acres)
Mark Twain NF	873	1,098	13
Huckleberry CA	19	17	5
Big Sugar Creek SP	41	36	4
Flag Spring CA	32	23	9
Roaring River CA	18	14	2
Roaring River SP	23	22	3
Busiek SF and WA	13	15	3
Pilot Knob CA	11	17	3
Total	1,030	1,242	42

Table 8-2. *Significant occurrences of restorable Compton and Pierson limestone glades protected in Missouri state parks (SP), Missouri Department of Conservation wildlife management lands (WA), Missouri Department of Conservation areas (CA), and USFS national forest (NF).*

GRAND FALLS CHERT GLADES

Number of glades	69
Minimum size	0.01 acre
Maximum size	14 acres
Total acreage (sum)	121 acres
Mean size	1.8 acres
Maximum perimeter	1.7 miles
Total perimeter	18 miles
Mean perimeter	0.3 mile
Pattern density	Scattered
Classification – Terrestrial Natural Communities of Missouri (Nelson, 2010)	Chert glade natural community
Classification – International Ecological Classification Standard (Nature Serve, 2009)	Ozark Chert Glade

Table 8-3. *Statistical summary of Grand Falls Chert glades.*

MISSOURI DISTRIBUTION

The Grand Falls Chert is a localized silicified sequence (chert) restricted to outcrops along Shoal Creek in the vicinity of Joplin in Newton County, in extreme southwest Missouri. Distribution of the formation is sporadic and discontinuous. Forty-three chert glades occur in the valley of Shoal Creek in the southern city limits of Joplin. The second area of 26 chert glades is situated in the upper reaches of Shoal Creek some 30 miles southeast in Barry County. According to Robertson (1967), chert outcrops previously labeled as Grand Falls Chert (but not located along Shoal Creek near Joplin) are assigned to the Reeds Spring Formation, Elsey Formation or Keokuk Limestone. These units contain chert outcrops scattered throughout; however, they are not stratigraphically consistent. Density is scattered.

TOPOGRAPHIC RELATIONSHIP TO DISTRIBUTION PATTERNS

A visit to the locally famous Wildcat City Park and the Grand Falls of Shoal Creek in southwest Joplin immediately uncovers the reason for the distribution pattern of Grand Falls Chert glades throughout southwest Missouri. Shoal Creek has cut through the Burlington Keokuk into the Elsey and Reeds Spring formations exposing the thick glassy siliceous Grand Falls Chert. In northwest Barry County, Shoal Creek exposes another local cluster of glades between 1,200 feet and 1,250 feet in elevation. It is not until 30 miles northwest and downstream near Joplin that at 900-foot elevation Shoal Creek incises and exposes the Grand Falls Chert north and south of the bridge along Interstate 44. In this vicinity, the formation is as much as 80 feet thick, thus more expansive chert glades ascend from tributary stream valleys to lower hillslopes adjacent to the streams.

Figure 8-12. *Grand Falls Chert glade at Wildcat Glade Natural Area in Joplin, Newton County.*

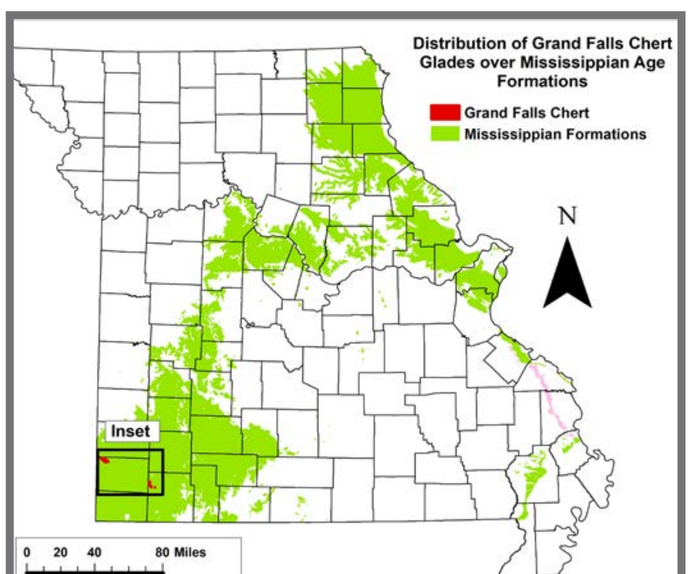

Figure 8-13. *Missouri distribution of Grand Falls Chert glades. Note inset.*

LITHOLOGY, SHAPE AND SIZE

Grand Falls Chert consists of a massive, thick, nearly impenetrable bed of silicified chert rock with thicknesses 24 feet to 40 feet at the type section, and rapid transitions to lenticular beds of brown, fine-grained limestone within short distances (Thompson, 1995). Where exposed on the surface as a glade, the chert appears as a glassy, shiny, tightly cemented, knotty and gnarled rock with splintery fractures and fine brecciation. The chert is light gray but weathers light yellowish brown to dark brown. The chert breaks into distinctly sharp fragments and jagged boulders that are scattered on the glade surface.

Of all the glade rock types, there is no confusing the appearance and identification of Grand Falls Chert from other glade-producing formations. The largest glade at 14 acres occurs on private property near Redings Mill about 1 mile southwest of Wildcat Park and the Grand Falls. Many chert glades are nearly flat with slopes less than 5%. A few exceptions occur including Wildcat Glade Natural Area where a large chert glade occupies a small valley with slopes upward of 20%.

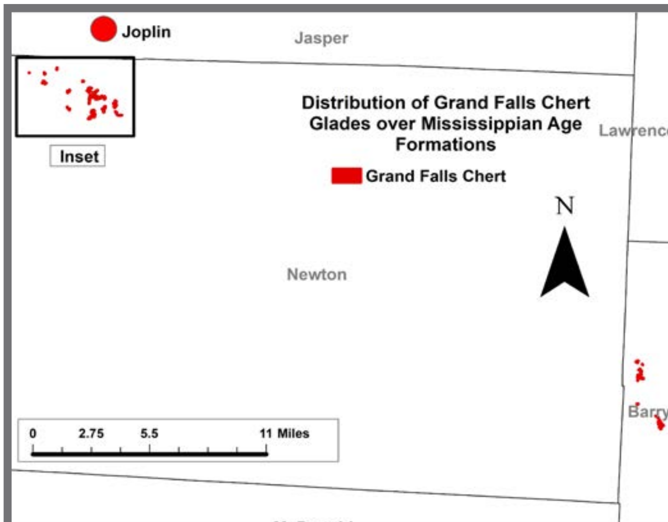

Figure 8-14. *Expanded view of inset in Figure 8-13, indicating distribution of Grand Falls Chert glades of southwest Missouri. Figure 8-15 is of inset in upper left corner.*

Because of their flatness in valley floors, and being subject to some flooding scour, most glades are rectangular with often ragged, irregular borders. When present, intermittent streams have cut into the massive chert bed forming deep, narrow trenches with steep vertical chert ledges as high as 10 feet. Moderately sloping glades often contain ragged chert ledges and boulders stepping down two to five feet. Where subject to flooding in valley floors directly adjacent to Shoal Creek, most occur as exposures of flat bedrock, especially along upper Shoal Creek in Barry County. During winter and spring, or summer rain events, ephemeral ponding occurs in depressions or holes created along fractures in the impervious chert bedrock. Otherwise, harsh dry conditions rapidly deplete what little soil moisture exists and dries out vegetation during hot summer months.

PUBLIC LAND LOCATIONS AND FUTURE PROTECTION OPPORTUNITIES

Thirty-one of the 43 known chert glades in the Joplin cluster occur within a 3-square-mile area centered in Wildcat City Park. At 80 acres, this area contains nearly 70% of all the known chert glade acres in Missouri. Conservation organizations should explore additional protection measures to protect a significant chert glade complex situated immediately south of Spring Creek near the village of Redings Mill.

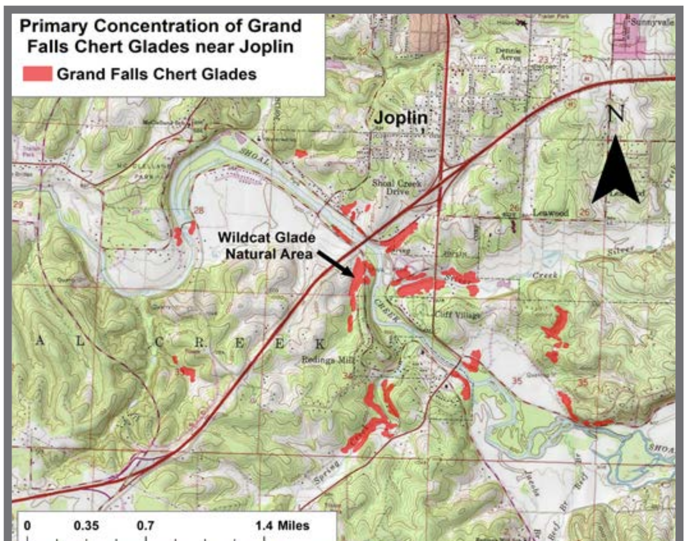

Figure 8-15. *Local distribution and topography of Grand Falls Chert glades in the Joplin city limits.*

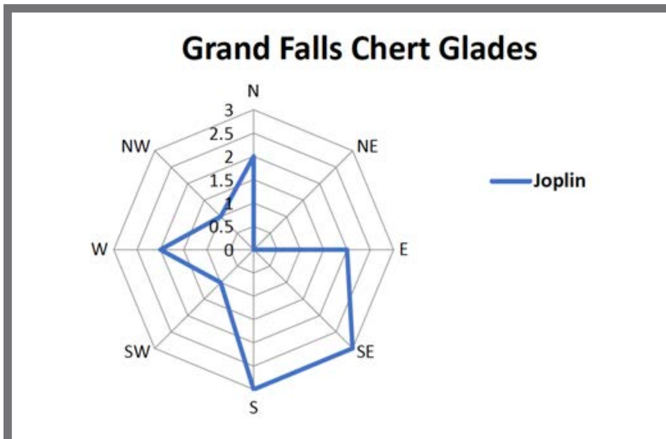

Figure 8-16. *Only 14 of 43 glades examined along Shoal Creek near Wildcat City Park in Joplin (Newton County) had enough slope and aspect to count in the chart. The remaining 26 (60%) occupy essentially level valley floors and floodplains.*

Figure 8-17. *Chert glade 30 miles southeast of Joplin in northwest Barry County. Many of the 26 mapped glades here (totaling 30 acres) are clustered along upper Shoal Creek and are subject to scouring by moderate flooding.*

Figure 8-18. *Burlington and Keokuk limestone glade near Elkton, Hickory County.*

BURLINGTON AND KEOKUK LIMESTONE GLADES

Number of glades	6,518
Minimum size	0.02 acre
Maximum size	138 acres
Total acreage (sum)	12,727 acres
Mean size	2.0 acres
Maximum perimeter	10 miles
Total perimeter	2,217 miles
Mean perimeter	0.3 mile
Pattern density	Dense to widespread
Classification – Terrestrial Natural Communities of Missouri (Nelson, 2010)	Limestone glade natural community
Classification – International Ecological Classification Standard (Nature Serve, 2009)	Ozark Limestone Glade

Table 8-4. *Statistical summary of Burlington and Keokuk limestone glades.*

MISSOURI DISTRIBUTION

The Burlington and Keokuk limestone (Burlington and Keokuk) is the dominant Mississippian-age formation extending across the broad smooth plain of the Springfield Plain Subsection and northward into the extreme western portions of the Osage River Hills Subsection. Limestone glades originating from the Burlington and Keokuk are not prominent across the smoothest portions of the highest Springfield Plateau (south and west of Springfield) due to the deep overburden of weathered residual soil. It is not until the plateau diminishes to the north that dissections of the Little Osage, Sac and Pomme de Terre rivers (tributaries to the Osage River above Warsaw) expose limestone bedrock and glades form. More than 12,000 acres of glades occupy an area (Fig. 8-19 inset) nearly 100 miles long by 25 miles wide stretching from Benton and Henry counties to the north southward to Lawrence and Greene counties. These glades are dense where streams and rivers have carved into the thick Burlington and Keokuk limestone. The most extensive area occurs on the hilly terrain immediately bordering Truman Lake in southwestern Benton, eastern St. Clair and western Hickory counties. This region is the predominant Burlington and Keokuk limestone glade-producing region with more than half (3,680) of the 6,518 glades located here, totaling 8,600 of the total 12,727 acres. To the south, five other widespread glade clusters occupy the dissected hills and upland plains near Stockton Lake reservoir. Here, 2,478 glades totaling 3,830 acres occur. Isolated expanses of other Mississippian and Pennsylvanian formations are unevenly distributed and intermingle with the northern extent of Burlington and Keokuk glades. Pennsylvanian-age channel sandstone strata interrupt and dissect the Burlington and Keokuk north and west of Springfield.

Elsewhere, two isolated widespread clusters of more than 300 Burlington and Keokuk glades are situated on the west and east side of the Missouri River where it bisects Moniteau and Boone counties. Isolated glades also occur in Lincoln County, and along the Eureka Springs Escarpment descending into the White River Hills.

TOPOGRAPHIC RELATIONSHIP TO DISTRIBUTION PATTERNS

The 200-foot-thick Burlington and Keokuk limestone is the predominant glade-producing formation on the Springfield Plateau. A few glades are exposed on the smooth level plateau near Springfield (Wilson's Creek National Battlefield). It is not until the Sac, Pomme de Terre, and Osage rivers and tributaries begin cutting into the plateau that numerous glades are developed. Unlike other limestone and dolomite glade types, the Burlington and Keokuk limestone formations are the highest on the landscape. Their resistance to weathering leaves them capping the rounded hills and ridges especially in west-central Missouri. Several hundred large glades blanket hilltops descending in all directions, especially around Truman Lake (Fig. 8-21) and Rocky Barrens Conservation Area (Fig. 8-22). Highest on the Springfield Plateau just northwest of Springfield, the Rocky Barrens Conservation Area complex occurs on rolling gently dissected hills and plains between 1,050 feet and 1,250 feet in elevation. Slopes range from near zero on hilltops and plains to 20% on hillslopes. The plateau imperceptibly falls to 900 feet northward in and around Truman Lake in Benton County. Here, dense areas of large glades (some more than 100 acres) are situated across hillcrests, ridges and saddles descending in all directions on high smooth side slopes. The radial aspect chart in Figure 8-24 depicts datasets from three locations and reveal aspects for Burlington and Keokuk glades vary widely. The more than 180 glades in the Warsaw dataset (located southwest of Warsaw, Missouri) represent a small portion (within 12 square miles) of the extensive dense grouping of glades found throughout the Truman Lake Reservoir drainage., More than 100 glades occur on nearly level crests and plateaus of hilltops, but are not depicted in the chart. The nearly 200 glades in the vicinity of Rocky Barrens Conservation Area in Greene County occur primarily on west and east to southeast aspects, but at least 35 occupy level to gently sloping high terrain. In contrast, the nearly 100 glades confined to 12 square miles of hilly terrain in the western portion of the Outer Ozark Border Subsection in Moniteau County (Jamestown glades) exclusively face southwest and south. At this location the presence of a deep loess layer over the woodland-forested landscape along the Missouri River likely suppresses glade development on north to east-facing hillslopes. Glades here occur between 740 feet to 860 feet in elevation.

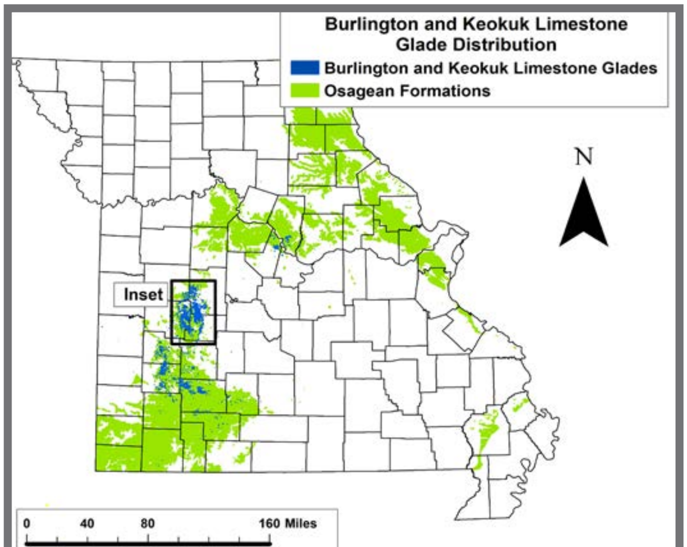

Figure 8-19. *Distribution of Burlington and Keokuk glades and associated Osagean formations. Note inset.*

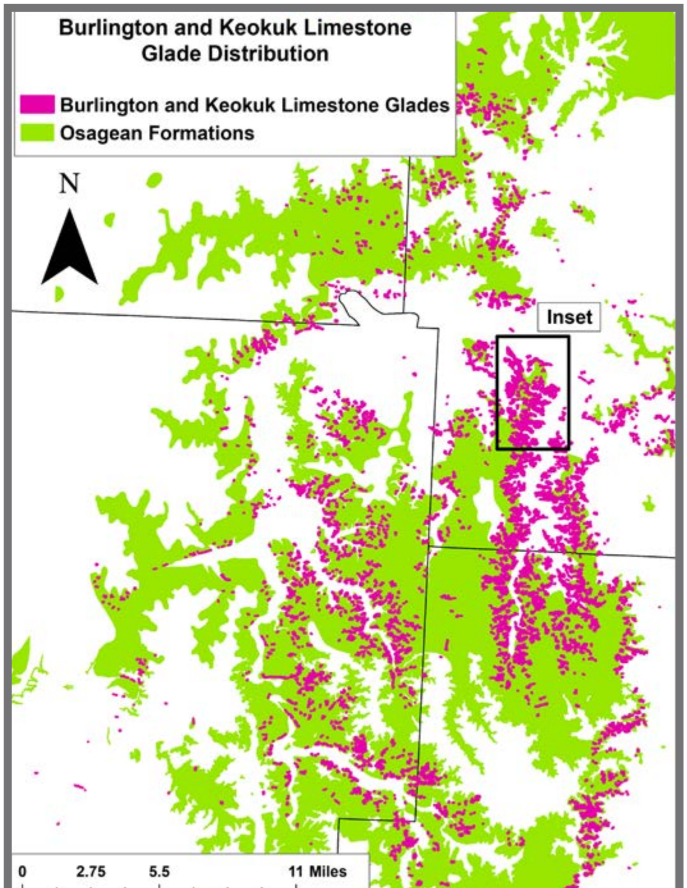

Figure 8-20. *Inset from Figure 8-19.*

LITHOLOGY, SHAPE AND SIZE

On Burlington and Keokuk limestone glades, the exposed bedrock and stony surface is coarse-grained, crystalline crinoidal limestone. Burlington and Keokuk formations have more than 260 species of crinoids, more than any other formation in Missouri. So prominent and distinctive is this characteristic that one can identify the glade type by this feature alone. Pure crinoidal rock is light gray to white, but brownish when weathered and impure. Discontinuous bands and nodules of chert are prevalent. The Burlington underlies the lithologically similar Keokuk Limestone, which is often difficult to near impossible to differentiate (Thomson, 1986). They are often grouped together as the Burlington and Keokuk Formation. Their combined thickness is around 200 feet. It is possible that limestone glades may also occur in conjunction with the Warsaw Limestone that overlies the Keokuk Formation.

Across the glade surface, Burlington and Keokuk Limestone weathers into a smooth, shallow soil surface over somewhat shallow rock layers. Mixed grasses, herbs, and mosses cover most rock (except steep exposures or pastureland). The surface is often strewn with scattered flattened boulders and stratified rock ledges.

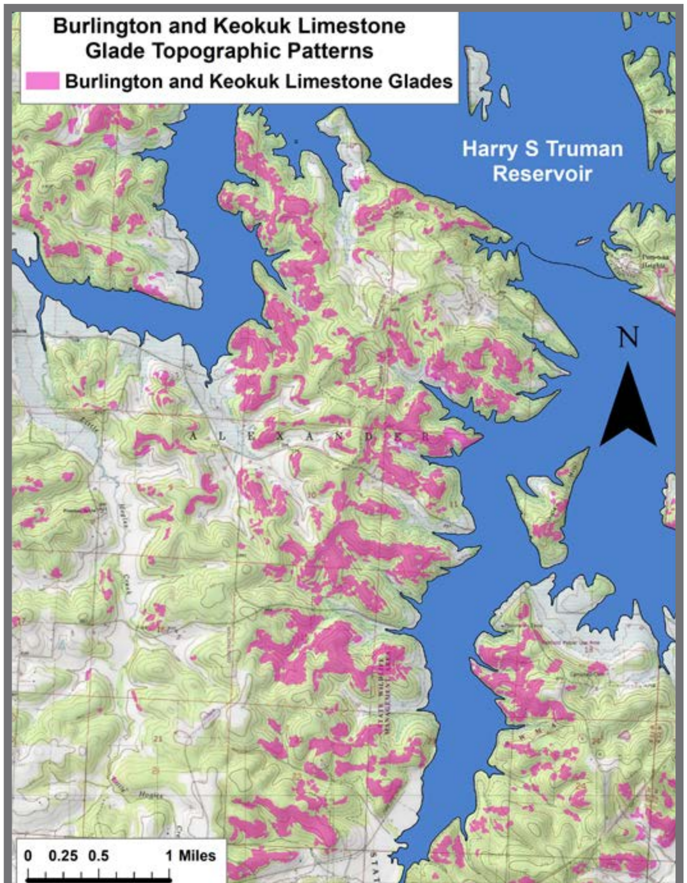

Figure 8-21. *Burlington and Keokuk glade topographic pattern near Warsaw, Benton County. Expanded view of inset in Fig. 8-20.*

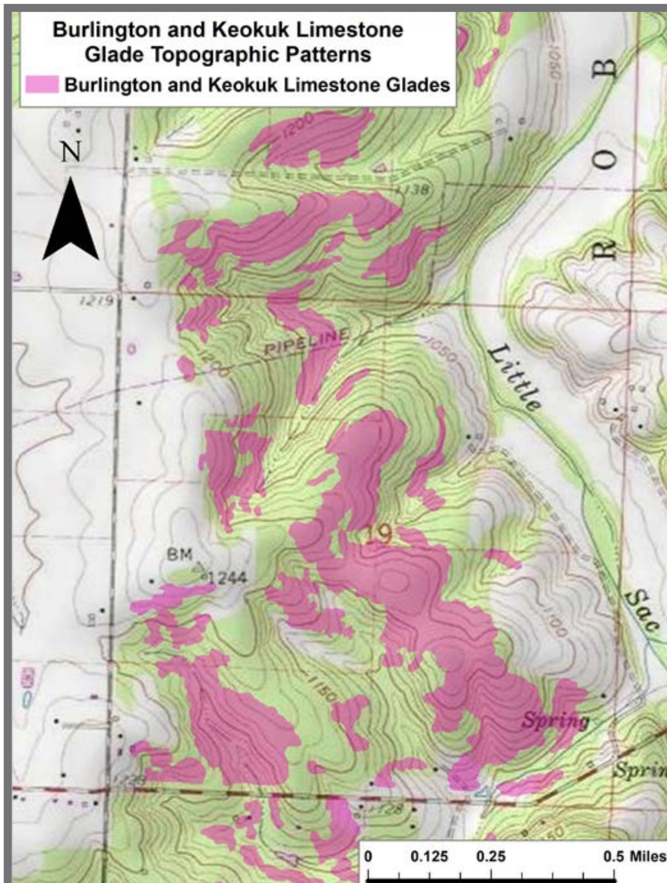

Figure 8-22. *Burlington and Keokuk limestone glades at Rocky Barrens Conservation Area, Greene County.*

Evenly-aged, predominantly 80- to 100-year-old red cedar forms an extensive, nearly solid closed canopy over many of the glades found in wooded hilly sections adjacent to Truman Lake. In contrast, many barren overgrazed glades occur across open grassy pasturelands where former prairie and savanna covered the landscape, particularly west of Willard and in the western portions of the distribution range. Because of the extensive cover of red cedar in the Truman Lake region, this required several field visits to verify whether red cedar occurred on glades or on old overgrown pastures or croplands, especially on ridges and hilltops. Apparently, decades of dense red cedar cover establish a deep needle organic layer covering glade bedrock (Fig. 8-23), often making it difficult to readily identify and map overgrown glades.

The 50 largest glades (greater than 21 acres) occupy the dissected 150-foot to 200-foot relief rolling hills and ridges at the southern end of Truman Lake along the Pomme de Terre River arm (Fig. 8-21). At 2,217 acres, these 50 glades have the second highest total with a mean of 44 acres. These large glade shapes are highly irregular complex patches with distorted, multiple extended, often twisting arms, their shapes determined by the patterns of elevated hilltops and ridges. The largest glade is 138 acres; however, it is situated adjacent to (within 500 feet) another 128-acre glade. Many of the larger glades have complex perimeters, some of which span 10 miles. Unlike other limestone and dolomite glade types, few of the total 6,500 glades are crescent-shaped. Most shapes in the Burlington and Keokuk Limestone do not follow the conventional influence of otherwise stratified bedrock layers.

PUBLIC LAND LOCATIONS AND FUTURE PROTECTION OPPORTUNITIES

Nearly 200 glades totaling 297 acres occur within Truman Reservoir Management Lands (managed by MDC), Benton County. These glades need active ecological restoration. Rocky Barrens Conservation Area protects 16 glades totaling 176 acres, including one single glade of 82 acres. Harry S Truman State Park (Missouri Department of Natural Resources), Benton County, actively manages 50 glades totaling 62 acres.

Figure 8-23. *Decades of red cedar growth following historic open range grazing now cover extensive areas of Burlington and Keokuk glades around Truman Lake in Benton County.*

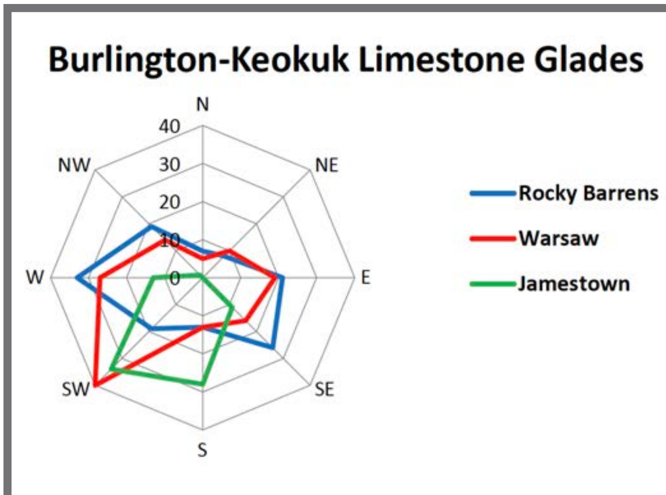

Figure 8-24. *Burlington and Keokuk aspect chart for Rocky Barrens (Greene County), Warsaw (Benton County), and Jamestown (Moniteau County) directional polygons show their respective glades cross all aspects excepting the Jamestown glades.*

Figure 8-25. *Partial crinoid and bryozoan fossils in the Burlington and Keokuk Limestone Formation located two miles southeast of Warsaw in Benton County. Photo by Vaughn.*

Chapter 9. Pennsylvanian-Age Glade-Producing Formations

During the Pennsylvanian age, sea levels rose and fell multiple times creating a cyclical pattern with periods of heavy erosion and deposition. These fluctuating sea levels caused shorelines to migrate back and forth across the western and northern areas of the state. During periods of lower sea level, large rivers created vast channels and deltas on the exposed continent, only to be covered with water and have marine sediments deposited again. Vast areas of the Great Plains, including western and northwestern Missouri, served as a relatively stable platform for the deposition of hundreds of cyclical sedimentation events. Throughout the period, repeated sea level oscillations resulted in changes of swampy shorelines, movement of river deltas and channels, and episodic erosion cycles all of which resulted in a complex stratigraphic sequence of coal, sandstone, shale, limestone, mudstone and conglomerate.

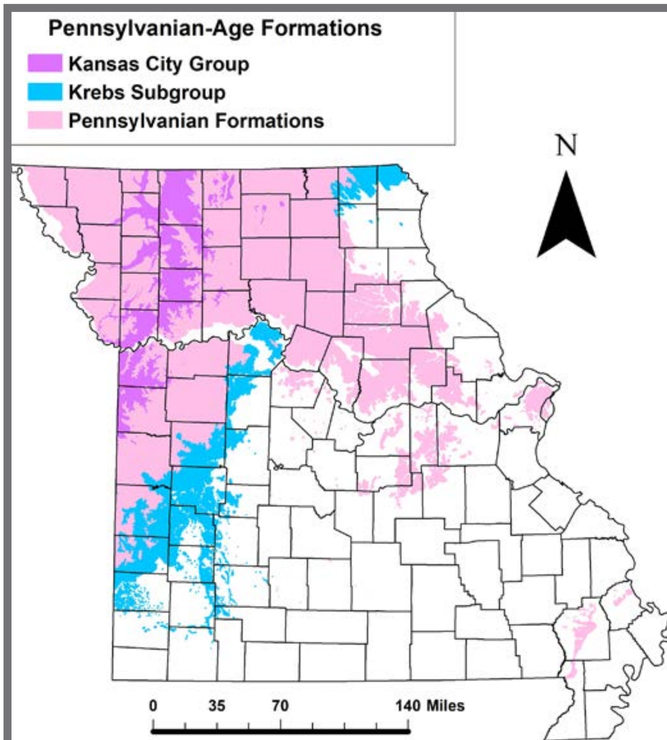

Figure 9-1. *Distribution of Pennsylvanian-age formations in Missouri.*

MISSOURI DISTRIBUTION

Channel sandstone glades are restricted to the west-central Ozarks in the Springfield Plains and extreme southwestern portion of the Osage River Hills ecological subsections in St. Clair, Cedar, Dade and Lawrence counties (Fig. 9-1).

The extent of mapped channel sandstone glades (lower case as not a formal geologic unit name) is associated with perhaps hundreds of "groups or sets" of Pennsylvanian-age riverine channel sand deposits within the Atokan Group and the Krebs subgroup of the Cherokee Group extending from Saline County southwestward 160 miles to Jasper County. In addition, glades have been mapped on the basal Graydon conglomerate as well as on other units of the Cherokee group in Lawrence and Greene counties. Hinds and Greene (1915) offer explanations for the origins of the sandstone fill, perhaps being sediments washed from the emerged Ozark Plateau. Today, most geologists agree that these elongated channel sand fillings or bar deposits (sometimes referred to as "shoestring sands") are basal fills of different ages within the Pennsylvanian. However, tens of thousands of years of erosion, inundation by seas, overtopping by ocean sediments, glacial till, loess deposition and weathering obliterated most channel sand deposits, leaving only remnant exposed outcrops. It is upon these remnant outcrops where channel sandstone glades occur. Indeed, the patterns of glades may in fact reveal new information about the otherwise poorly understood relationships and patterns of the channel sands of southwest Missouri.

CHANNEL SANDSTONE GLADES

Number of glades	1,092
Minimum size	0.04 acre
Maximum size	37 acres
Total acreage (sum)	1,129 acres
Mean size	1.0 acre
Maximum perimeter	3.1 miles
Total perimeter	229 miles
Mean perimeter	0.2 mile
Pattern density	Scattered
Classification – Terrestrial Natural Communities of Missouri (Nelson, 2010)	Sandstone glade natural community
Classification – International Ecological Classification Standard (Nature Serve, 2009)	Ozark Sandstone Glade

Table 9-1. *Statistical summary of channel sandstone glades.*

Figure 9-2. *Designated more than 40 years ago, the relatively small 20-acre Bona Glade Natural Area in Dade County protects one channel sandstone glade and a limited occurrence of other associated natural communities.*

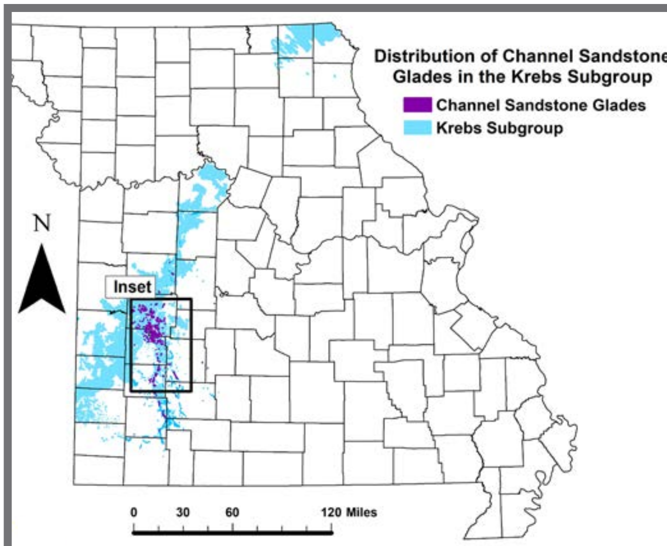

Figure 9-3. *Distribution of channel sandstone glades associated with the Krebs Subgroup. Note inset expanded in Figure 9-4.*

The greatest extent of channel sandstone glades is centered along an 80-mile-long axis beginning in St. Clair County to the north and ending in eastern Lawrence County to the south. In St. Clair County, these glades occur in several widespread clusters, extending 10 to 15 miles on either side of the axis and into northern Cedar County. From there, the glades follow several 5 to 10-mile-wide narrow bands of scattered to isolated sandstone outcrops and extending south 35 miles into Lawrence County.

TOPOGRAPHIC RELATIONSHIP TO DISTRIBUTION PATTERNS

The topography for channel sandstone glades ranges from nearly level plateaus to dissected plains associated with the Springfield Plain Subsection and extreme southwestern portion of the Osage River Hills Subsection. The position of the channel sandstone deposits often dictates the slope and shape of the glade, whether on a hilltop or plateau, side slope, or valley.

The widespread complex of glades near Blackjack in St. Clair County straddles the Arnica anticline. It is thought the anticline may have uplifted the channel sandstones upward, thus exposing them at the surface to considerable erosion and allowing formation of the glades. In this immediate vicinity, sandstone glades generally range from 800 to slightly more than 900 feet in elevation and occupy higher nearly level crests of hills and plains. Several miles southeast of Blackjack (Fig. 9-5), streams carved into what appears to be a continuous and expansive erosion-resistant sandstone deposit, perhaps a broad alluvial fan or delta, some 40 feet thick and capping the surrounding plains and upper hill-slopes. Stream erosion and undercutting of weaker shales beneath the sandstone layer have formed a high ledge or cliff rim running along the upper slopes of hills and headwater cuts. Blocks of sandstone boulders and some talus have broken away and slumped downslope from these ledges. In this area, glade development occurs along the top edge of the exposed rim.

In contrast, many of the exposures of channel sands in Lawrence County and the Chesapeake and Sac rivers appear to be associated with faults. On the south side (uplifted) of the Chesapeake River (ranging from 1,150 to 1,250 feet in elevation) and the north side of the Sac River faults, the sandstones act as more of a true channel sand. However, in the graben (downthrown middle between the two faults), units widen out and appear to have a more horizontal extent, possibly an ancient alluvial fan deposited into a basin.

LITHOLOGY, SHAPE AND SIZE

In Greene County, Thomson (1986) described the lithology of the sandstone as varying from a fine to coarse-grained quartzose sandstone to conglomerate with pebbles within the conglomerate composed of reworked Ordovician- to Mississippian-age chert. Eason and Laudon (1984) described the sandstones in the Graydon Springs area (Polk County) as a fining upward conglomeratic to sandstone sequence, and proposed a meandering stream/point bar sequence as the origin. Originally, the channel sand deposits in Greene and Lawrence counties were suspected to be consistent with the Warrensburg/Weldon River deposits; however, later paleontological research on plant fossils indicated the deposits to be much older (Howe, 1982). As with any erosional remnant, the geographic expression and thicknesses of these sandstones vary greatly. Hines and Greene (1915) indicated that the Moberly channel of the Warrensburg/Weldon River was nearly 40 miles long while the Warrensburg channel was nearly 50 miles long. In both the Warrensburg and the Weldon River channels, the thickness of the sandstone units were thought to be at their greatest at about 200 feet. Outside of the more discrete channels of the Warrensburg/Weldon River sandstone, outcrops are much thinner and discontinuous.

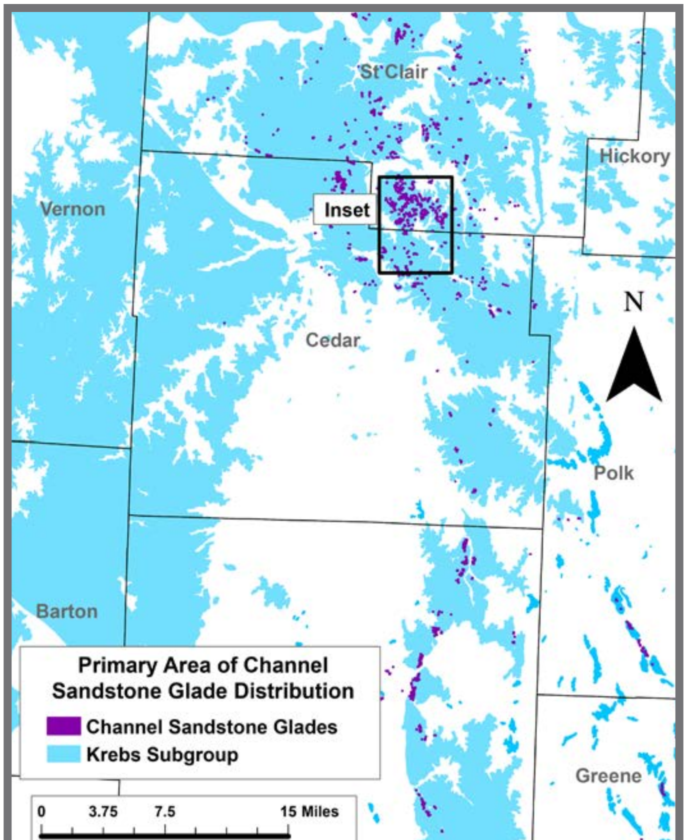

Figure 9-4. *Inset from Figure 9-3 depicting primary distribution of channel sandstone glades in west central Missouri. Figure 9-5 is an expanded view of the above inset.*

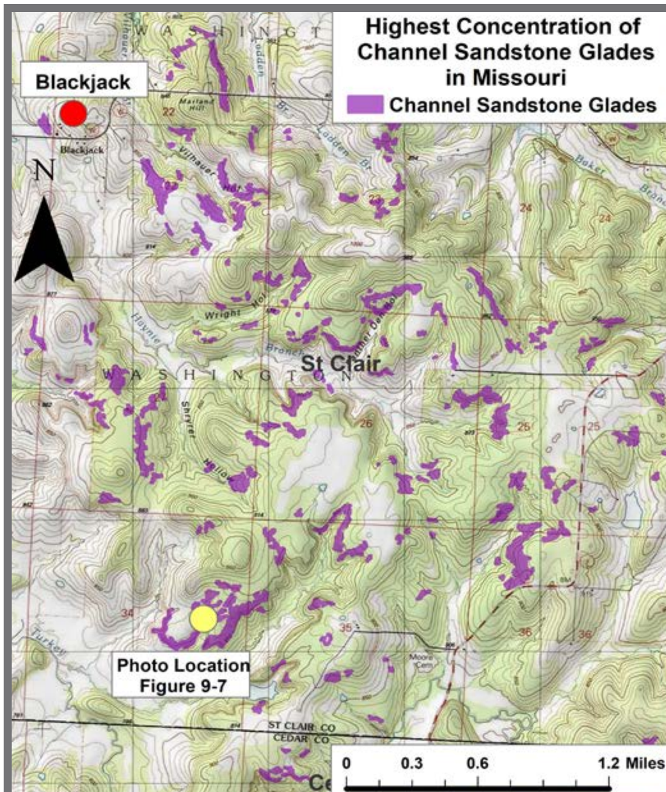

Figure 9-5. *Local channel sandstone glade distribution in relationship to topography. Glades occur along equal elevation contours associated with the erosion-resistant sandstone bedrock located high on the landscape. Yellow dot marks photo location shown in Figure 9-7.*

Other channel sandstones of varying thicknesses of 5 to 25 feet across their range are mixed with sedimentary layers of shale, coal, conglomerate, and some limestones. Because most channel sandstone deposits have limited horizontal extent, they do not erode into alternating layers of step and ledge bedrock topography as is characteristic of dolomite and limestone units. Many slab bedrock glades in the southern extent of their development area are nearly level, containing solution pockets and depressions, which filled with water during wet periods or winter (Bona Glade Natural Area in Dade County). Glades in the northern portion of the area near Blackjack in St. Clair County develop on steeper midslopes and contain larger boulders and ledges (Lichen Glade Natural Area in St. Clair County). Mosses and lichens cover extensive areas, helping to distinguish them from limestone and dolomite glades during mapping of aerial imagery.

Glade shapes are sinuous, twisting and often paralleling equal elevations along the crest of hills, or occurring in lines (elongated channels), especially in the southern extent. Their aspect is dictated by the direction in which the hillslope faces. Many have no aspect (Fig. 9-6) where their slopes range from near zero to 15% and relief is no greater than 15 feet. Steeper aspects occur on glades situated adjacent to larger streams and rivers. Figure 9-6 depicts aspect assigned to 294 mapped glades in three regions. Of this number, the graph excludes 82 glades with generally neutral aspects. The 161 glades concentrated in a 12-square-mile area near Blackjack represent the largest channel sandstone glade complex of the total Missouri distribution. While the majority are oriented south and west, 35 face northwest to east. The dataset from the Lichen Glade complex contains 39 glades with many oriented southeast to southwest. The Stockton Lake complex in the Dade County dataset contains 91 glades of which 58 are depicted in the graph. Approximately 32 (36%) occur on neutral aspects. The Stockton complex is distributed along a 35-mile-long, 5-mile-wide north to south axis. These uncommon glades may have 25 to 30 feet of relief.

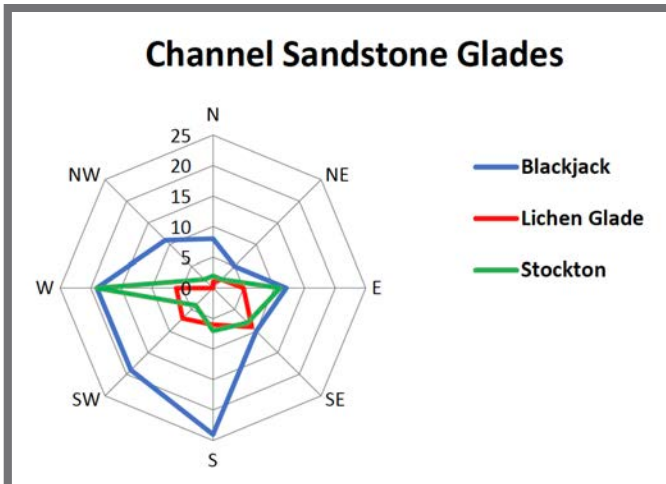

Figure 9-6. *Graph depicts radial aspects assigned to a cross section of 294 mapped glades of various sizes in three areas of the total distribution.*

Compared to other sandstone glade types, channel sandstone glades are the largest with a mean size around 1 acre as compared to a 0.6-acre average for Lamotte and St. Peter Sandstone glades and a 0.5-acre average for Roubidoux Sandstone glades. Approximately 25% or 273 of the 1,092 glades are greater than 1 acre. The largest channel sandstone glade is 37 acres with a 3.1-mile perimeter as compared the Lamotte sandstone glades at 11 acres, and 7 acres for the Roubidoux and St. Peter Sandstone formations. The largest 50 glades total 376 acres with a total perimeter of 48 miles. Forty glades totaling 73 acres occur along a 3-mile linear stretch meaning that despite being mapped separately, these glades are densely packed and thus ecologically considered as one.

PUBLIC LAND LOCATIONS AND FUTURE PROTECTION OPPORTUNITIES

More than 30 glades totaling 75 acres (including one at 22 acres) occur on Truman Reservoir Management Lands. Stockton Lake Management Lands in Cedar County contain 36 totaling 72 acres. Other public lands include Taberville Prairie and Lichen Glade natural areas in St. Clair County with nine acres each. Numerous channel sandstone glades occur on U.S. Army Corps of Engineers lands, including the largest glade at 37 acres and Bona Glade Natural Area both in Dade County.

The above glade parcels pale when compared to the cluster of 215 channel sandstone glades found within the rugged scarped hills on private lands centered within the Haynie Branch watershed in St. Clair County (Fig. 9-7). More than 220 acres of sandstone glades occur in a complex of localized steep sandstone cliffs and canyons. Devoid of EORs, this rugged 10-square-mile region is deserving of natural features inventories and future protection.

Figure 9-7. *One (yellow circle Fig. 9-5) of more than 200 channel sandstone glades distributed across 25 square miles of undeveloped lands in St. Clair County, Missouri. Locate person right of center for scale.*

Figure 9-8. *Channel sandstone glade in level upland prairie. Taberville Prairie Natural Area, St. Clair County. Note the depressions on the bedrock surface.*

BETHANY FALLS LIMESTONE GLADES

Number of glades	238
Minimum size	0.03 acre
Maximum size	4.0 acres
Total acreage (sum)	125 acres
Mean size	0.5 acre
Maximum perimeter	0.7 mile
Total perimeter	35 miles
Mean perimeter	0.1 mile
Pattern density	Locally widespread at Lake Jacomo; scattered to isolated elsewhere
Classification – Terrestrial Natural Communities of Missouri (Nelson, 2010)	Limestone glade natural community
Classification – International Ecological Classification Standard (Nature Serve, 2009)	Not included

Table 9-2. *Statistical summary of Bethany Falls limestone glades.*

MISSOURI DISTRIBUTION

Nearly all the 238 mapped Bethany Falls Limestone glades (formally Bethany Falls Limestone Member) are in Jackson County east of Kansas City in the northernmost portion of the Osage Plains Section. Surprisingly, the first iteration of the Natural Glade shapefile included only 14 glades on the Bethany Falls Limestone Member. The 2018 Natural Glade shapefile added an additional 224 glades, a 1,600% increase. The initial mapping project did not include the Bethany Falls glade region, assuming their extent was known. This elevated the significance of the formerly known extent of glades from being an anomaly to one of ecological importance.

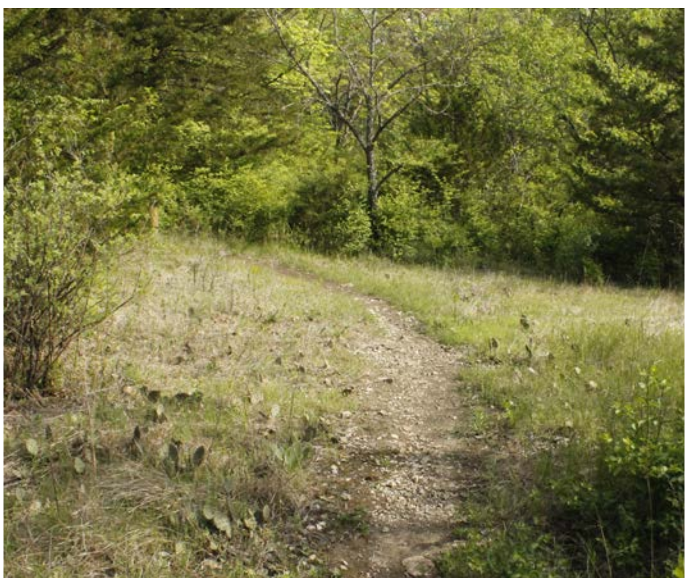

Figure 9-9. *Bethany Falls Limestone glade at Lake Jacomo, Jackson County Parks and Recreation Association.*

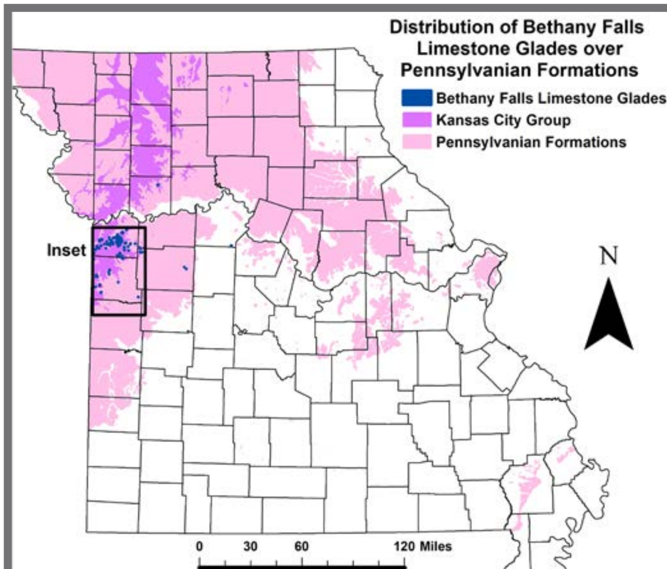

Figure 9-10. *Distribution of Bethany Falls glades over Pennsylvanian formations. Figure 9-11 is an expanded view of the inset.*

TOPOGRAPHIC RELATIONSHIP TO DISTRIBUTION PATTERNS

The 350-foot-thick Pennsylvanian-age Kansas City Group contains many subgroups and geologic members of shales, fossiliferous limestones and sandstones. The group covers an area 30 to 50 miles wide across plains and gently rolling hills stretching from 60 miles south of Kansas City to 150 miles north to the Iowa border. Only in Jackson County do Bethany Falls glades occur, owing to the downcutting of the Blue River and its tributaries south and east of Kansas City near where the mouth of the river intercepts the Missouri River. North of the Missouri River, ancient glacial retreats deposited a thick mantle of glacial till and windblown loess, allowing little opportunity for glade development. However, south of the glacial advancement the Blue River and tributaries have carved 200-foot-deep valleys in the Kansas City vicinity. The erosion-resistant Bethany Falls Limestone Member crops out generally at an elevation between 800 and 940 feet as a vertical ledge interspersed by slumping limestone blocks. Glades sporadically occur on the nearly level bench situated on top of the exposed ledge, often in interrupted chains along south and west-facing hillslopes.

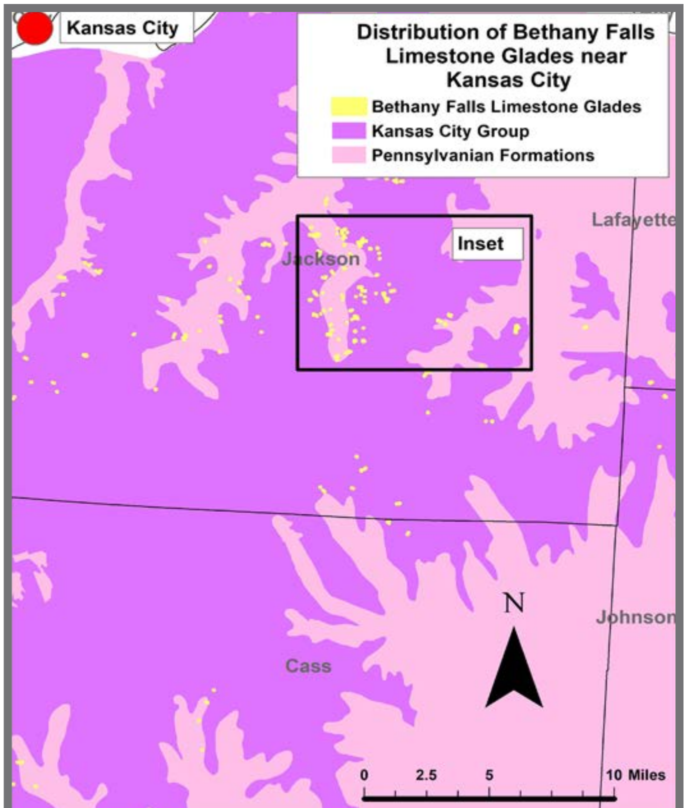

Figure 9-11. *Primary area of distribution for Bethany Falls glades around Kansas City. Inset is expanded in Figure 9-14.*

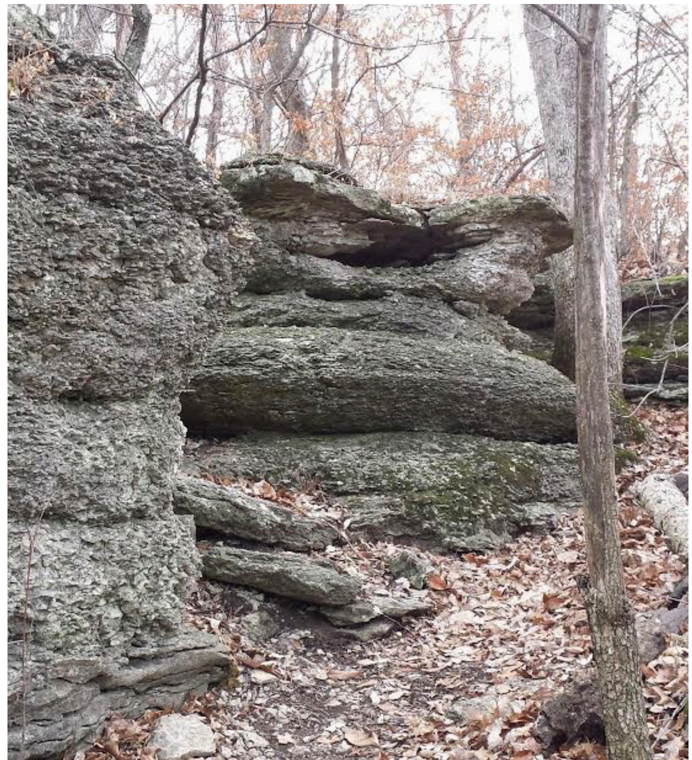
Figure 9-12. *Upper part of the glade-producing Bethany Falls Limestone Member. Ledges and joint blocks form an exposed midslope layer along the many dissected valleys in Swope Park and around Lake Jacomo.*

LITHOLOGY, SHAPE AND SIZE

The Bethany Falls Limestone Member of the Swope Formation is a Pennsylvanian-age limestone bedrock unit located in western Missouri. It is a light-gray, dense, thin-bedded limestone that is chert-free and commonly contains fossils. Thickness of the unit averages approximately 20 feet but can range from about 12 to 30 feet. The lower, thin-bedded limestone portion varies from 1 to 20 feet in thickness while the upper part varies from 7 to 15 feet. The unit, especially the upper part, is a prominent outcropping unit in Western Missouri. Several dozen geologic formations within the Pennsylvanian subsystem are characterized by prominent limestone units with interbedded shales. However, no other limestone of the Missourian Series exhibits such prominent exposures (Fig. 9-12) as Bethany Falls Limestone joint blocks and ledges (Moore, 1949).

Due to the limited thickness of the rock layer, glades tend to be linear and small with a mean of 0.5 acre. The 238 mapped glades total 125 acres with the largest being only four acres. Their shapes range from linear to oblong elliptic. Slopes range from 0 to 15 degrees. The longest glade is 1,200 feet.

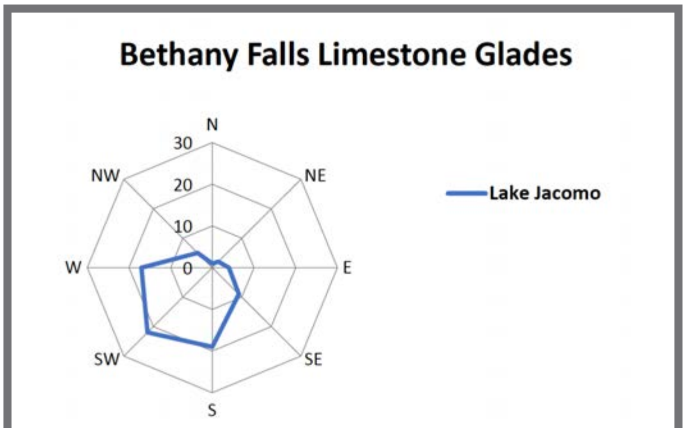

Figure 9-13. *Radial aspect chart for Bethany Falls glades indicates the glades occupy south and west aspects among the gentle hills surrounding Lake Jacomo in Jackson County. Nearly 100 (42%) are concentrated within 18 square miles centered on Lake Jacomo.*

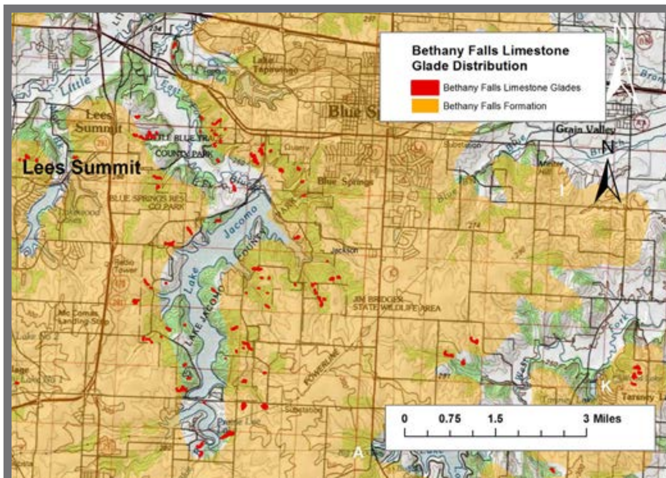

Figure 9-14. *Nearly one-half of the total 238 Bethany Falls glades occur within the watershed drainage of Lake Jacomo in Jackson County.*

PUBLIC LAND LOCATIONS AND FUTURE PROTECTION OPPORTUNITIES

More than 90 Bethany Falls Limestone glades (38%) occur on lands administered by Jackson County Parks and Recreation. The majority (83) occur in Lake Jacomo County Park. Blue River Glades Natural Area in Swope Park (Jackson County Parks and Recreation) protects several good quality glades. Unfortunately, many glades are islands amid a sea of pervasive bush honeysuckle thickets (*Lonicera maackii*) and carpets of cheatgrass (*Bromus tectorum*). Many are worthy of restoration efforts.

Figure 9-15. *Bethany Falls Limestone glades in the vicinity of Lake Jacomo Park, Jackson County. Note the dominance of eastern prickly pear (Opuntia humifusa) in the second image.*

Chapter 10. Miscellaneous Glade-Producing Formations

The miscellaneous category includes a varied assortment of glades difficult to group because they do not share similar characteristics. Additionally, their limited numbers, small size, questionable quality, and lack of definitive plant associations further leave their inclusion in question. However, without examining them in the field, they are included herein to encourage further study and assessment to determine if they qualify for potential natural community status, or as variations best suited in an existing natural community (Nelson, 2010).

Altogether, few glades have been reported on the following geologic formations. These formations range in age from the Ordovician-age Gunter Sandstone Member of the Gasconade Dolomite to various Pennsylvanian-age formations.

- Chattanooga Shale (Devonian).
- Hannibal Shale (Mississippian).
- Northview Formation (Mississippian).
- Warsaw, Salem and St. Louis limestones (Mississippian).
- Various cyclothems (Pennsylvanian).

SHALE GLADES

Number of glades	79
Minimum size	0.1 acre
Maximum size	10.6 acres
Total acreage (sum)	92 acres
Mean size	1.2 acres
Maximum perimeter	0.9 miles
Total perimeter	17 miles
Mean perimeter	0.2 mile
Pattern density	Scattered to isolated
Classification – Terrestrial Natural Communities of Missouri (Nelson, 2010)	Not included
Classification – International Ecological Classification Standard (Nature Serve, 2009)	Not included

Table 10-1. *Statistical summary of shale glades.*

The MSDIS 2018 Natural Glades shapefile includes shale glades in assorted geologic units. Should field examination take place, it is probable several the 79 shale glade polygons would be deemed not suitable for inclusion in the shapefile. Steyermark (1963) reported shale glades in the unglaciated prairie region of southwest Missouri. Nelson and Ladd (1983) described shale glades in their "Preliminary Report on the Identification, Distribution, and Classification of Missouri Glades," which was subsequently described in Yatskievych (1999). However, Nelson (2010) removed shale glades as a natural community, recognizing it as a variation of woodlands and prairies underlain by shale parent material. Delineating shale rock types is difficult for several reasons. First, teasing out shale signals in imagery is very challenging. Second, shales are often directly associated with or a component of other glade-producing rock types. Third, shale exposures often are artifacts of human disturbance, especially livestock grazing, all-terrain vehicle abuse and excavation. Finally, shales are found in a variety of geologic units including Devonian-age Chattanooga Shale, Mississippian-age Northview and Warsaw formations in east-central Missouri, Hannibal Shale in the northeast part of the state, and cyclothem deposits of Pennsylvanian-age. Due to these difficulties, shale glades were mapped based on lithology rather than separating them into specific geologic formations. A few EORs refer to some of these shale units, but discussions appear uncertain.

The authors have verified Northview and Chattanooga shale glades at several locations, which have aided in interpretation and mapping of Northview shale glades. However, confidence in precise delineation of the shale type (if even shale) is best approached with further field validation. Some shale glades of the Northview intersect with Compton and Pierson limestone glades.

Figure 10-1. *Limited occurrences of Northview Formation shale glades occur in conjunction with Compton and Pierson limestone glades. The authors field checked this glade on MTNF near Shell Knob, Barry County.*

MISSOURI DISTRIBUTION

Most shale glades occur along the periphery of the transition between Ordovician-age Jefferson City Dolomite and the initial narrow zone of Mississippian-age Kinderhookian Series geologic units. Nearly half of the mapped shale glades (most likely Northview) occur in steep head valleys of stream tributaries where the Pomme de Terre River carves into the Springfield Plain Subsection just south of Wheatland in Hickory County. A few isolated Devonian-age shale glades occur in northeast Missouri in Pike County; however, those occurrences are thought to be associated with the lower Mississippian-age Hannibal Shale. Moss and lichen-dominated glade-like barrens dry oak-dominated woodlands of northern Missouri are excluded.

TOPOGRAPHIC RELATIONSHIP TO DISTRIBUTION PATTERNS

Most shale glades occupy south and west-facing slopes of gentle to steep upper slopes and steep head valleys of drainages. Some occupy saddles of narrow ridges.

LITHOLOGY, SHAPE AND SIZE

Missouri shales are derived from the compaction of fine clay particles deposited in oceans, river deltas and lagoons. Thin shale units were commonly deposited during the Pennsylvanian-age cyclothem depositional sequence; however, the thickest and most extensive shale units occur within the Ordovician through Mississippian ages. Since shales often break into thin, splintery layers due to the parallel orientation of clay particles, they are said to have a fissile nature. Unlike other types of bedrock, weathering of fissile shales often leaves compacted but loose fragments of these small flakes during glade development. When appearing in massive units, shales are difficult to distinguish due to their similarity of particle size and silt. However, claystones can often display a curvilinear fracture pattern resembling conchoidal fracturing while siltstones appear to have a blockier fracture pattern. While often gray, variations occur in mineral composition, organic content, and redox levels that may cause shale color to vary. Reduction or oxidation of iron present in the shale can alter coloration; when reduced the shale is often gray or green and if oxidized can have a red nature. For example, the Northview shale is often gray to green while Chattanooga Shale is dark gray to black due to its high organic content. Depending on the depositional environment, a variety and number of organic materials and other minerals ranging from calcite, dolomite, iron oxides and gypsum. Even phosphorus nodules may also be present within the shales. During glade development, the resulting mineral and chemical variations can influence the presence or absence of obligate plant species. No vascular plant species truly obligate to shale glades are known in Missouri.

PUBLIC LAND LOCATIONS AND FUTURE PROTECTION OPPORTUNITIES

A few shale glades (possibly human-caused erosional exposures) occur on MTNF in southwest Missouri, particularly Barry County.

MERAMECIAN LIMESTONE GLADE

LIMESTONE GLADE NATURAL COMMUNITY

Limestone units present within the Meramecian series produced 19 glades totaling 19 acres in eastern Missouri, mostly near St. Louis. These units include the lower limestone portion of the Warsaw Formation, Salem Formation, and the St. Louis Limestone (MSDIS Natural Glades shapefile). Except for the shales of the upper Warsaw, these bedrock units are predominately limestone with their thickest occurrences of 250 to 400 feet in east-central Missouri and thinning toward the north and west. Chert, while not common, is present and in the Salem Formation, takes on a distinctive rounded bulls-eye appearance to the nodules (Fig. 10-2). At this time, no glades have been identified in the Warsaw and Salem formations of west central and southwestern Missouri.

Figure 10-2. *A distinctive bull's eye chert nodule embedded in limestone of the Salem Formation. MoDNR photo by Pierce.*

Chapter 11. Summary and Analysis of Missouri Glades

With 182,464 acres, Missouri tops all states in the eastern half of the U.S. for having the highest acreage of glades (Fig. 11-1). Of the 18 geologic units with glade occurrences, five units represent 94% of the total 182,464 acres (Fig. 11-2). The Jefferson City Dolomite glades are the largest at 132,216 acres or 72.5% of the total. The remaining 13 geologic units and glade types make up only 6% of the total acreage.

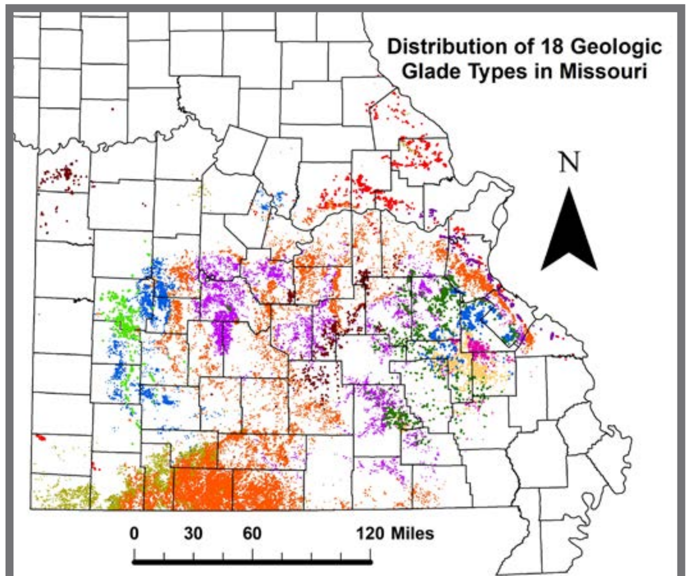

Figure 11-1. *A color collage of the 18 geologic glade distribution maps featured in each chapter. Glade borders are slightly exaggerated increasing the size of glades to make them more visible. Colors represent different glade types.*

The 2018 Missouri Natural Glades shapefile can provide dozens of data subsets useful in answering many statistical questions about Missouri glades. Some analysis is useful to answer several of the more important questions resulting from the distribution and patterns of the various glade types. For example, how many acres of each glade type are found across Missouri counties? Are there correlations between glade distributions and ecological units? Are glade types floristically distinct and worthy of protection? Are there any anomalies in the patterns?

Figure 11-4 depicts the total glade acres for each Missouri county. Few if any glades occur in northern Missouri counties, and in the Mississippi River Alluvial Basin Section of southeast Missouri. Taney County in south-central Missouri has the highest acreage at 53,823 acres. Within the county, the 38,263-acre Protem NE 7.5′ quadrangle contains 10,288 glade acres (Fig. 11-5) capturing the highest concentration and density of glades in the eastern U.S. Nearly 30% of the quadrangle is mapped glade. Total number of glades in each county is higher or lower than the county glade acres. For example, 91 Bethany Falls Limestone glades occur in Johnson County near Kansas City. However, the total number of glades is 200.

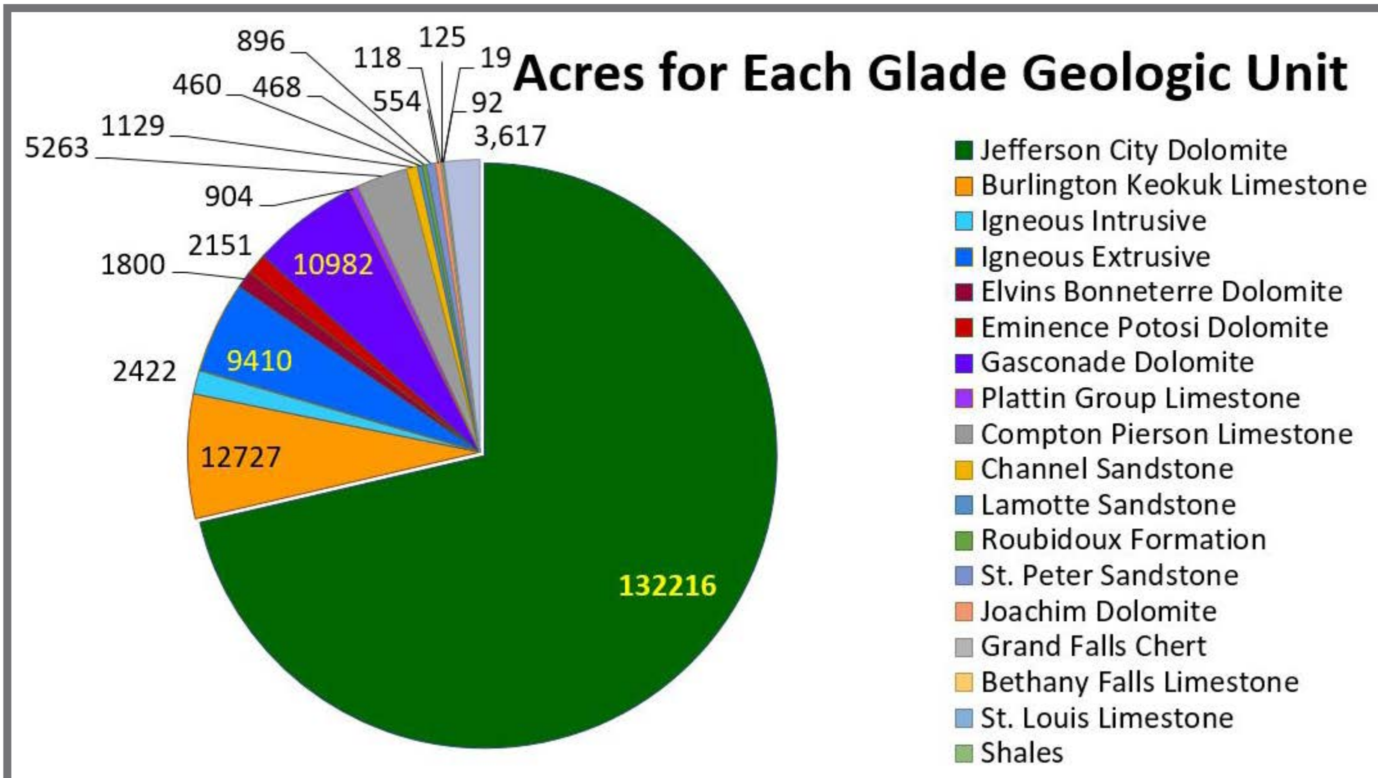

Figure 11-2. *Relative acres for nine geologic glade types each totaling 1,000 acres or more. Note the 3,617 acre pie sliver is the total of the eight glade types depicted in Figure 11-3, with each type less than 1,000 total acres.*

How do Missouri's glade distributions correlate with Missouri ecoregions? Differences in landform, soils, and vegetation distinguish the 16 ecological subsections in the Ozark Highlands of Missouri (Nigh and Schroeder, 2002). Glades were mapped in 19 ecological subsections (Fig. 11-6) with most occurring in the Ozark Highlands Ecological Section. Lesser numbers are found in the Osage Plains Section (near Kansas City) and the Central Dissected Till Plains Section, mostly in the Mississippi River Hills Subsection.

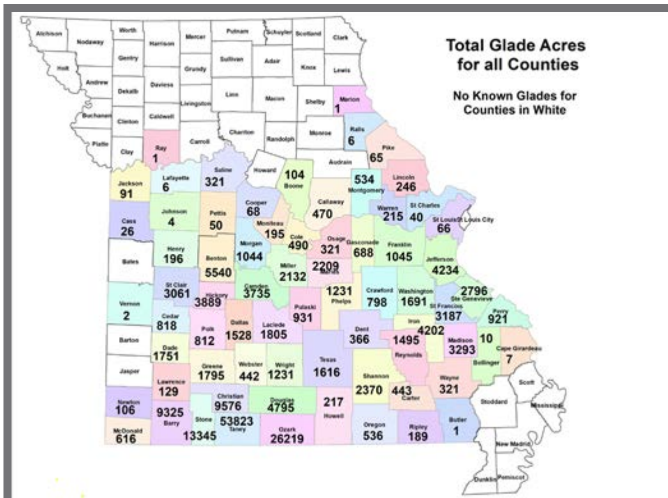

Figure 11-4. *Total glade acres (all geologic units) in each Missouri county. Counties in white have no known glades. Total number of glades in each county are higher or lower than the acres. Taney County, in southwest Missouri, has the most with 53,823 acres.*

Glade geologic units are dependent on the geology directly beneath them. Eons of erosional cycles have down cut through the concentric rings of geologic formations surrounding the ancient Ozark dome. Many of the ecological subsection boundaries of the Ozark Highlands (Nigh and Schroeder, 2002) embrace the dissected hills and valleys of major rivers draining off the ancient dome. This erosional process has exposed many glades; however, glade types are not dependent on just the hills, but on the geology beneath them. Specific glade types are not confined to watersheds alone, unless the ecological area matches the boundary of a specific Missouri geologic unit. For example, the presence of igneous rock types is a primary criterion used in delineating the St. Francois Knobs and Basins Subsection. Significantly smaller numbers of igneous glades do occur in surrounding subsections. In contrast, the Osage River Hills, Gasconade River Hills, and Meramec River Hills subsections are delineated across several concentric rings of various-age geologic formations along the flanks of the Ozark Highlands uplift, and thus contain a variety of glade types. The White River Hills Subsection strongly correlates with the primary distribution of Jefferson City Dolomite glades. However, significant regions of dolomite glades also occur throughout the Jefferson City Dolomite along the north and east flanks of the Ozark dome.

Where the Ozark Highlands dome dips abruptly along its northern and eastern flanks, it forms a narrow 220-mile-long band between one to 20 miles wide known as the Inner Ozark Border. Numerous geologic formations are tightly packed and sandwiched along this band, along with over 6,000 acres on ten geologic glade types.

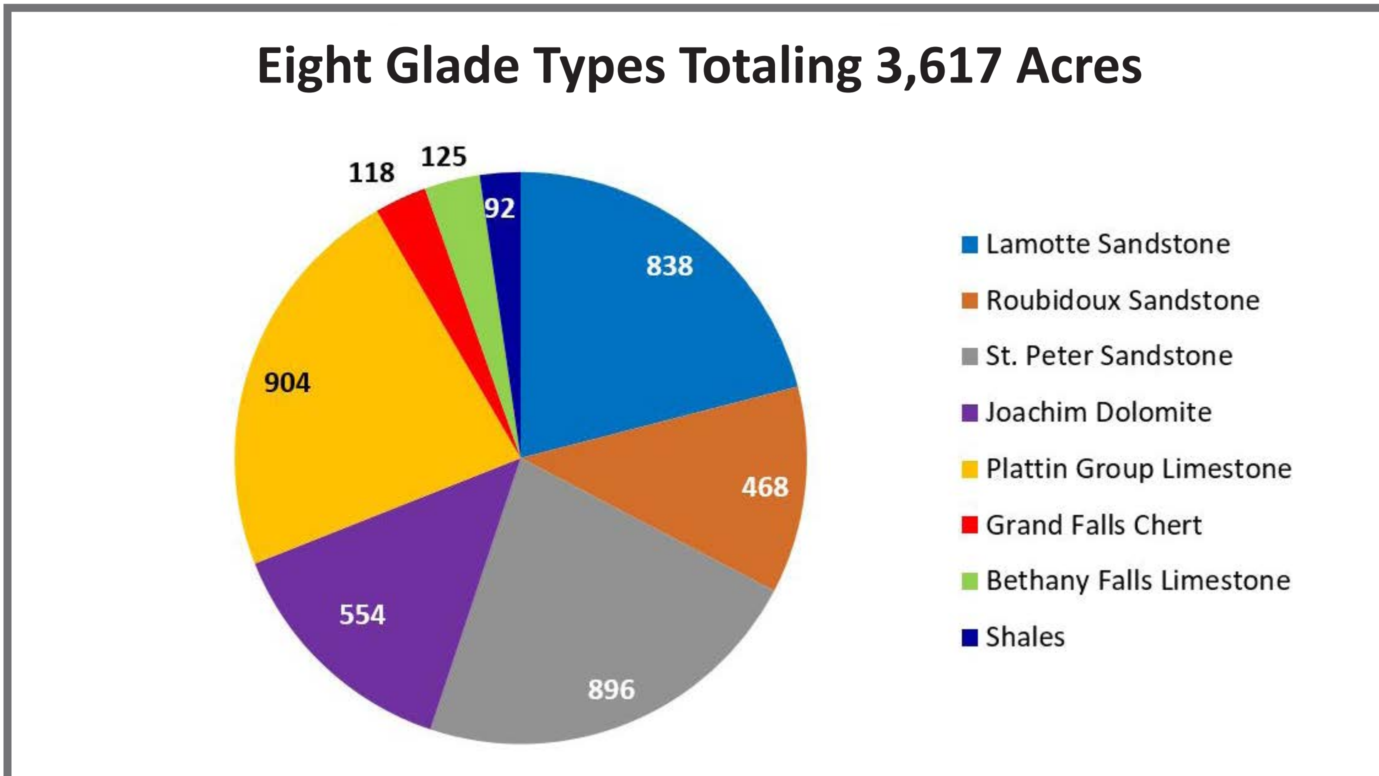

Figure 11-3. *The 3,617-acre sliver in Figure 11-2 encompassing eight glade geologic units is expanded to depict the relative size of the geologic units ranging from 92 to 904 total acres each.*

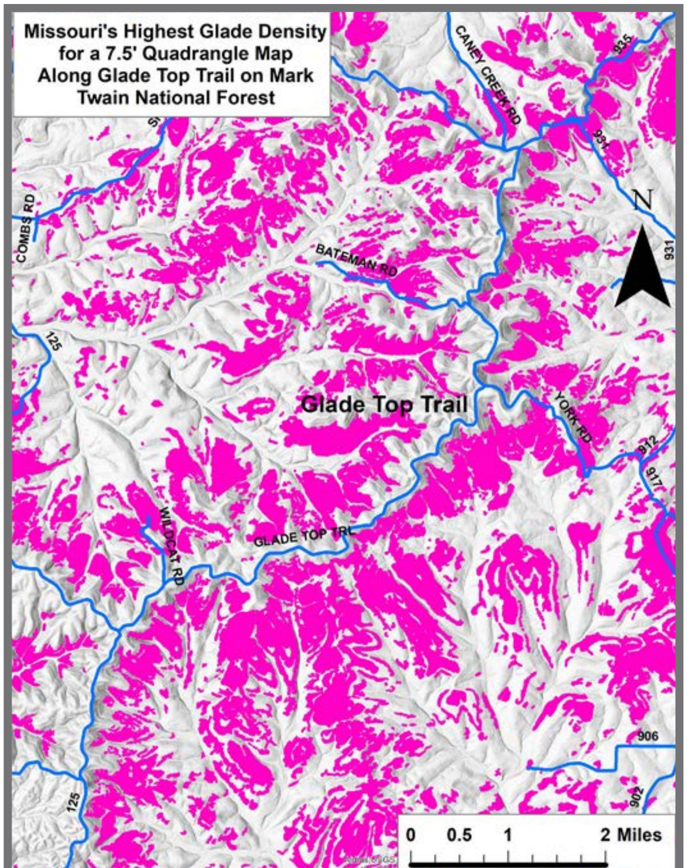

Figure 11-5. *The Protem NE 7.5' quadrangle map harbors the highest density of glades in the eastern half of the U.S.*

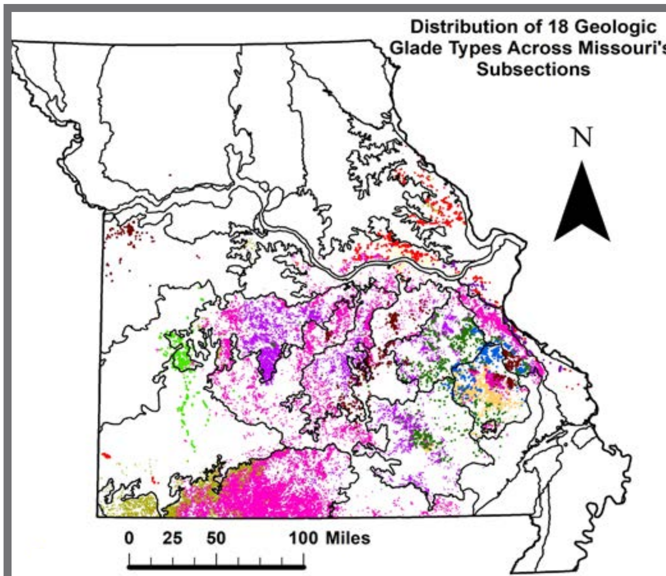

Figure 11-6. *Distribution of all mapped glades across Missouri's subsections (Nigh and Schroeder 2002). Note the absence of glades north of the Missouri River Alluvial Plains, which are nearly nonexistent due to several historical advances of glaciers, and the deposition of deep loess.*

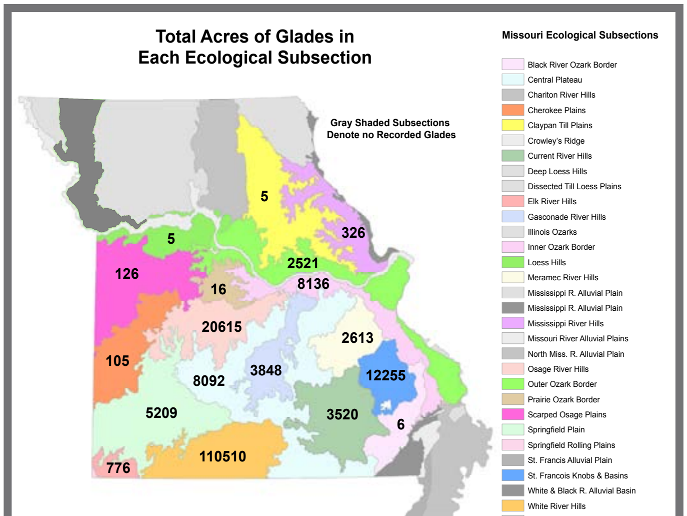

Figure 11-7. *This Missouri map depicts total glade acres for each subsection (Nigh and Schroeder 2002). Note: Glade acres north of the Missouri River Alluvial Plains are nearly nonexistent due to several historical advances of glaciers, and the deposition of deep loess.*

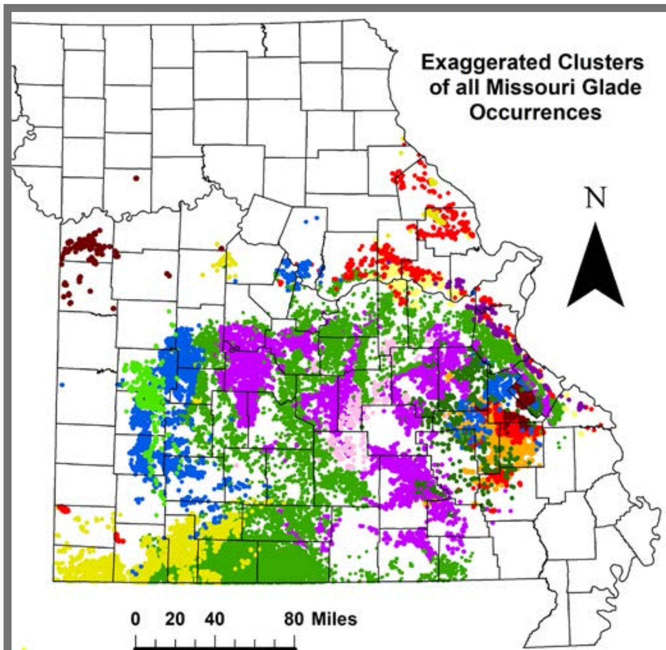

Figure 11-8. *Borders of the 18 glades shown in Figure 11-6 are exaggerated to clarify their relative distribution, location, and density. The overlapped colors suggest that additional respective glade types might be located therein. The diverse color clusters in eastern Missouri attest to the highly variable and complex glade-producing geology of the region.*

Chapter 12. Conservation Implications

The Central Hardwoods Glade Conservation Assessment lists 118 glade plant species of conservation concern in Missouri. To preserve glade biodiversity and species viability, conservation planners need to determine the spatial distribution of these conservation targets. This inventory provides comprehensive spatial data on the distribution, substrate type and patterns of Missouri glades, which should facilitate additional inventory for species locations as well as set criteria for the most efficient and viable representation of protected or managed glade landscapes in Missouri.

Missouri's comprehensive glade map reveals the extent of previously unknown occurrences and patterns across the state's most important glade-forming geologic substrates. A high-resolution map facilitates additional floristic monitoring and research to determine whether the isolation of these patterns and differences in rock substrate soil chemistry influence the presence of distinctive plant associations, genetic variations, and new species locations. For the first time, authors of numerous published glade studies can revisit their works in the context of an all-important question: "What is the extent, distribution and pattern of the specific glade(s) being studied, and how does this new information influence and affect the need to revisit strategic glade conservation planning, design and conservation in light of previous efforts?" For starters, glade enthusiasts and researchers must expunge a deeply entrenched, widely accepted figure for total Missouri glade acres.

The 70-year-old assumption that 500,000 acres of glades (dolomite glades of the White River Hills) occur across Missouri is outdated. Many citations (Guyette and McGinnes, 1982; Kimmel and Probasco, 1980; and Probasco, 1978), various assessments, and others adopted the figure from a 1946 document entitled "The Twentieth Annual Report, Central States Forest Experimentation Station" (Mitchell, 1946). Page 61 of the report reads, "The 'glade' region of southwest Missouri is the largest area of natural grassland in the state. The 500,000 acres of glade are intermingled with forest areas."

The actual 182,464 acres determined by the methods in this study falls far short (a 63% reduction) of the 500,000-acre figure. The source of the original figure may have inflated the glade definition to include other associated grassland natural communities, particularly adjacent open rocky woodlands and savannas.

The acreage findings by Nelson and Ladd (1983) base estimates on select mapping, field evaluations, natural features inventories, and examination of black and white aerial photography. Today's modern resources and technology yielded a more precise estimate. As shown in Table 12-1, these estimates when compared to the 1983 study vary by higher and lower percentage of change. For example, Nelson and Ladd initially estimated sandstone glades at only 200 acres, making the four sandstone geologic units particularly rare. This estimate (as with other natural features) coincided with the early development of the Missouri Natural Areas Program, which designated many natural areas based on known opportunities and early natural features inventories. Historically, some natural areas were secured without comprehensive knowledge of the quality and extent of the full range of natural features from which to select high quality natural communities. The actual mapped acreage of sandstone glades is at least a 2,963 acre or 1,377% increase over the original Nelson and Ladd (1983) estimate. Large expanses of sandstone glades exist in the western region of the Ozarks, with channel sandstone glades representing a much larger area than earlier estimated. Exploration of the mapped sandstone glades reveals landscape-scale complexes where associated with other quality natural communities and watersheds. While most sandstone glade complexes are privately owned, many remain undeveloped and maintain a moderate level of natural quality.

Glade rock type	Estimated acres (Nelson and Ladd, 1983)	Mapped acres (Nelson et. al, 2021)	Percentage difference
Sandstone Glade	200	2,953	+1,377
Limestone Glade	3,000	19,019	+533
Dolomite Glade	400,000	147,703	-63
Igneous Glade	8,000	11,832	+48
Chert Glade	200	118	-41
Shale Glade	500	<100	-80
Total	500,000	182,464	-63

Table 12-1. *Comparison of glade rock type acres and percentage difference between Nelson and Ladd (1983) and the virtual GIS glade mapping.*

Glade ownership	Number glades	Total acres
Missouri Department Natural Resources-state parks	1,406	2,598
Missouri Department Conservation	4,556	7,886
Mark Twain National Forest	9,926	44,424
National Park Service	634	621
The Nature Conservancy	171	153
U.S. Fish and Wildlife Service	2	3
Corps of Engineers	2,518	6,910
Total	19,213	62,595

Table 12-2. *Glade ownership by federal, state and private natural resource management entities.*

Similarly, Compton and Pierson, and Burlington limestone glades exceed earlier estimations by 533%. More than 110,500 acres of Jefferson City Dolomite glades dominate the White River Hills Subsection. However, the geology data reveal more than 4,000 acres of Pierson and Compton limestone glades over the same landscape (Fig. 12-1). More exploration is needed in this region to determine if any restricted flora exists on the Compton Limestone compared to the Jefferson City Dolomite. For example, glades found underlain by the Burlington and Keokuk limestone in Greene County harbor the Missouri bladderpod (*Physaria filiformis*), a threatened species.

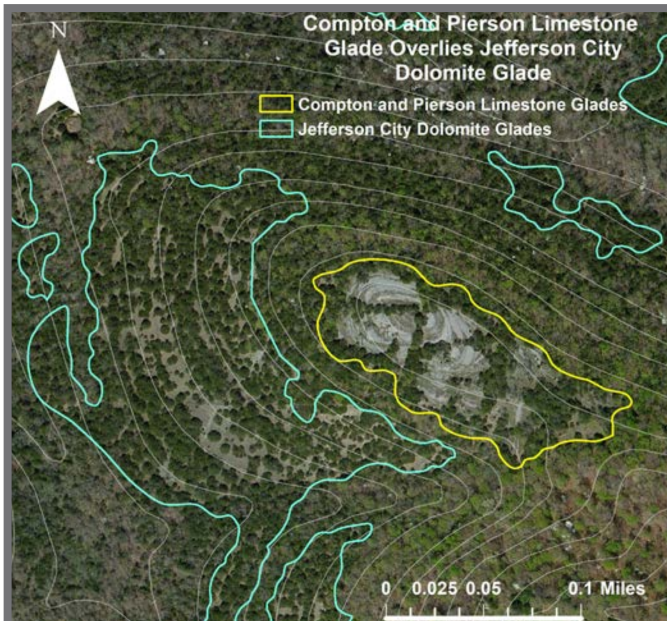

Figure 12-1. *A Compton Formation Limestone glade (outlined in yellow) caps a hilltop immediately above a Jefferson City Dolomite glade. Located 8 miles northeast of Roaring River State Park, Barry County.*

Missouri's glades qualify under the definition of "insular ecosystems" as subjects of the "Insular Ecosystems of the Southeastern United States" (Cartwright and Wolfe, 2016). Their assessment of similar island ecosystems (with emphasis on glades and other outcrop features) confirms the findings and conservation recommendations of the Central Hardwood Joint Venture Glade Conservation Assessment. Among the many concluding implications is that conserving glades may require the preservation of both discreet as well as large glade complexes across a full spectrum of sizes, shapes, patterns, geographic ranges and ecological conditions, rather than simply conserving a few large representative examples. Their assessment provides rationale both in context and contemporary references worthy of reading by Missouri's conservation organizations.

Fortunately, the Missouri glade map revealed many individual glades and glade groupings exist both within insular surroundings as well as in matrices of restorable woodlands and forests. The glade geology map unveils and displays patterns, complexes and distributions of 18 distinctive glade geologic units. Conservation organizations should revisit county inventories and compare the array of currently protected glade types to those newly mapped glades. New landscape designs that integrate the conservation implications presented in the above assessments may, as argued by Cartwright and Wolfe (2016), address issues relating to loss of genetic diversity, gene pool viability, and the capture of diverse environmental conditions.

Increasing landowner awareness should be a priority conservation initiative. Now available to the public, the virtual glade map reveals the presence of unique glade habitats on private lands. When informed and educated about the significance of glades, many landowners are willing to protect and manage them. Because the mapping process could not rapidly assess quality, rapid field assessments are necessary to recommend management actions most appropriate in determining restoration prescriptions. Thousands of acres of restorable glades should respond positively to careful application of ecosystem management treatments.

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Appendix

Appendix A. Statistical comparison of all glade types to 50 largest for each geologic unit.

Columns B through E are statistics for all of the mapped polygons for each geologic unit. Column F provides the perimeter length for the glade within the geologic unit that has the longest perimeter. Columns G through J are statistics for the largest 50 glades in each geologic unit.

A	B	C	D	E	F
Geologic unit	Total glades	Total acres	Largest glade (acres)	Mean size (acres)	Longest perimeter (miles)
Igneous Intrusive	3,220	2,422	31	0.7	3.5
Igneous Extrusive	9,183	9,410	67	1.0	6.3
Lamotte Sandstone	838	460	11	0.5	1.5
Elvins Dolomite and Bonneterre Dolomite	1,531	1,800	29	1.2	2.6
Eminence Dolomite and Potosi Dolomite	2,169	2,151	48	1.0	3.1
Gasconade Dolomite	12,033	10,982	38	0.9	4.3
Roubidoux Formation	1,012	468	4	0.4	0.5
Jefferson City Dolomite	50,416	132,216	968	2.6	56
St. Peter Sandstone	1,563	896	7	0.6	1.1
Joachim Dolomite	505	554	15	1.1	2
Plattin Group Limestone	1,505	904	11	0.6	1.4
Compton Limestone and Pierson Limestone	5,277	5,263	31	1.0	2.4
Grand Falls Chert	69	118	14	1.7	1.7
Burlington Limestone and Keokuk Limestone	6,518	12,727	138	2.0	10
Channel Sandstones	1,092	1,129	37	1.0	3.1
Bethany Falls Limestone	238	125	4	0.5	0.7
Miscellaneous Shales	79	92	10.6	1.2	1.9

A	G	H	I	J
Geologic unit	n Total acres	n Mean acres	n Total perimeter (miles)	n Mean perimeter (miles)
Igneous Intrusive	492	9.8	68	1.4
Igneous Extrusive	1,111	22	119	2.4
Lamotte Sandstone	122	2.4	22	0.4
Elvins Dolomite and Bonneterre Dolomite	521	10.4	58	1.2
Eminence Dolomite and Potosi Dolomite	490	9.8	47	0.9
Gasconade Dolomite	735	14.7	78	1.5
Roubidoux Formation	93	1.9	16	0.3
Jefferson City Dolomite	13,956	279	807	16
St. Peter Sandstone	175	3.5	30	0.6
Joachim Dolomite	262	5.2	34	0.7
Plattin Group Limestone	222	4.4	33	0.7
Compton Limestone and Pierson Limestone	557	11	54	1.1
Grand Falls Chert	114	2.3	17	0.3
Burlington Limestone and Keokuk Limestone	2,217	44	163	3.2
Channel Sandstones	376	7.5	48	1.0
Bethany Falls Limestone	70	1.4	15	0.3
Miscellaneous Shales	85	1.7	17.8	0.3